Section 5.0 Long-term Monitoring Data and Case Studies

A remining study conducted by EPA and PA DEP from 1984 through 1988 involved the statistical analysis of long-term abandoned mine discharge data from six sites in Pennsylvania. This study is described in Section 1.0 of this document. These sites and corresponding discharge data were selected because they contained a sufficient number of samples for examining mine drainage discharge behavior with univariate, bivariate, and time series statistical analyses following the algorithm shown in Figure 1.2a. The results of the statistical analyses are included in a series of eight unpublished reports prepared for EPA and PA DEP by Dr. J. C. Griffiths of the Pennsylvania State University. These reports are discussed in EPA's Statistical Analysis of Abandoned Mine Drainage in the Establishment of the Baseline Pollution Load for Coal Remining Permits (USEPA, 2001; EPA-821-B-01-014).

Sections 3.0 and 4.0 of this document describe the statistical methodology for establishing baseline for pre-existing discharges, and determined that the minimum baseline sampling duration and frequency is twelve samples in one year at approximately monthly intervals. Some discharge datasets in Pennsylvania contain more than twelve samples. These additional samples represent pre-mining baseline conditions of more than one year, and in some cases, discharges were monitored more frequently than monthly (e.g., weekly). In this Section, data from seven discharges at six sites previously studied by Griffiths are further examined by varying the baseline sampling interval and the number of samples used to establish baseline.

A benefit of further evaluation of the EPA/PA DEP remining study is that for some of the six sites, there are now approximately ten years of additional monitoring data. In addition, PA DEP has issued approximately three hundred remining permits since 1985, and for many completed sites there are complete historical records of discharge data from pre-mining baseline conditions, through active surface mining phases (open pit), to post-mining reclamation. Several examples of these long-term monitoring case studies are presented in this Section. These studies provide additional information on the magnitude and variability of natural seasonal variations, and show mining-induced changes in water quality and pollution load.

The long-term monitoring case studies in this Section can be used as examples of the application of the baseline statistical test described in Section 3.0 to actual remining datasets. The quality control approach to long-term baseline monitoring data is presented in the figures included in Section 5.3. Further examples of application of the baseline statistical test are presented in Appendix A.

5.1 A Comparison of Seven Long-term Water Quality Datasets

As part of the investigation documenting the baseline pollution load of pre-existing acid mine drainage (AMD) discharges, seven individual discharges with long-term water quality records were studied. Each of these seven discharges had datasets of at least 3 years duration, and were sampled at least monthly and as frequently as weekly. The seven discharges represent the three principal discharge behavior types (typical, slug, steady) discussed in Section 2.0. Table 5.1a lists the discharge behavior type, location, period of record, and number of samples for each of the seven long-term discharges evaluated.

Table 5.1a: Long Term Acid Mine Drainage Datasets

Dataset	Discharge Behavior Type	Location	Period of Record	Number of Samples
Arnot-3	typical	Tioga County, PA	1980 - 1983	82
Arnot-4	typical	Tioga County, PA	1980 - 1983	81
Clarion	typical	Clarion County, PA	1982 - 1986	79
Ernest	slug	Indiana County, PA	1981 - 1984	189
Fisher	typical	Lycoming County, PA	1982 - 1985	36
Hamilton	typical	Centre County, PA	1981 - 1985	109
Markson	steady	Schuylkill County, PA	1984 - 1986	99

The discharge behaviors discussed in Section 2.0 are summarized as:

1) <u>Typical Discharge Response</u>: Typical discharge response exhibits lower pollutant concentrations during high-flow periods and higher concentrations during low-flow periods. Most pre-existing discharges exhibit this type of behavior. These discharges tend to vary significantly, both seasonally and in response to individual recharge events. Five of the seven discharges listed in Table 5.1a exhibit this characteristic flow-response behavior (Arnot-3, Arnot-4, Clarion, Hamilton, and Fisher). All but the Clarion discharge are from relatively small (less than one square mile) underground mine complexes. The Clarion discharge emanated from a previously surface mined area.

2) <u>Slug Response</u>: The Ernest discharge emanates from an extensive unreclaimed coal refuse pile and exhibits highly variable behavior responding to individual precipitation events. It exhibits "slugger response" behavior. Increases in flow are not necessarily offset by decreased concentration and at times may even exhibit increased concentration due to the build-up of water-soluble acid salts in the unsaturated zone during periods of decreased precipitation or little recharge. These discharge types are extremely variable in flow and pollutant loading rates. They present the biggest challenge for accurate documentation of baseline pollution load.

3) <u>Steady response</u>: The Markson discharge illustrates steady response behavior typical of discharges from very large underground mine pools. These discharges vary seasonally, but because of their large ground water storage capacity, respond in a damped fashion and do not exhibit large changes in pollutant concentrations. These types of discharges are the least variable in terms of baseline pollution load. However, because loading rates change slowly, they are also the most susceptible to year-to-year variation in pollution load.

Baseline pollution load statistical summaries were calculated for each dataset using the exploratory data analysis approach discussed in Section 3.0. It is rare, however, that datasets of this duration and with as great a number of samples are available. Coal remining operations tend to be relatively small and run by small mining companies. The time available for a small coal operator to lease a reminable reserve, gather permit application information, obtain a permit, and actually mine and reclaim a site is frequently very short, making long-term baseline sampling periods infeasible. Moreover, because these operations tend to be economically marginal, large sample sizes with frequent sampling intervals can be cost-prohibitive. In view of these constraints, the primary concern with establishing a valid baseline is to determine the minimum sampling period and sampling interval which will yield statistically valid results.

The problem of determining the minimum number of samples and minimum sampling period that would yield statistically valid results was examined using the long-term datasets listed in Table 5.1a. It was first assumed that the baseline pollution load determined using all of the available samples over the entire period of record represents the most accurate baseline achievable. Reduced datasets (subsets) were then used to recalculate the baseline, and comparisons to the full dataset were made using the following data subsets: monthly sample collection, quarterly sample collection, and nine-month sample collection (February through October, excluding November, December, and January). The nine-month sample collection subset was used to test the possibility that excluding three months (typically November, December, and January are average flow months) could adequately represent the full water year. This comparison is presented in Table 5.1b. In addition, baselines were calculated for each full calendar year (full data baselines) to examine the extent of year-to-year variability in baseline pollution load (Table 5.1c).

For simplicity, this evaluation looks at net acidity (the principal parameter of concern and indicator of pH) and iron (the most prevalent metal present in AMD). Tables 5.1b and 5.1c list median loads and calculated approximate 95 percent confidence intervals (C.I.) around each median load. Assuming that the full data baseline best represents the true population median load, the percent error for each data subset is calculated as the difference between the full data baseline value and the subset baseline value, divided by the full data baseline value. Percent errors are presented in Table 5.1b. While no particular percent error is considered to be acceptable or unacceptable, these percentages are useful for examining which subsets provide the closest approximations of the full data baseline. Percent errors less than 10 are highlighted. Table 5.1c presents the median baseline pollution loads and 95 percent confidence intervals for each of the seven discharges studied. Years that do not show overlapping 95 percent confidence intervals are considered to be statistically different at the 95 percent significance level.

Table 5.1b: Comparison of Median Acidity and Iron Loads by Sample Period and Interval

Parameter	Full Data	9 Month Data	Percent Error	Monthly Samples	Percent Error	Quarterly Samples	Percent Error
Arnot-3							
Number of Samples	82	66		43		14	
Median Acid Load	72.3	84.1	16.32 %	73.9	2.21 %	72.3	0.00 %
Upper 95% C.I.	86.53	101.59		91.09		102.71	
Lower 95% C.I.	58.07	66.61		56.71		41.89	
Median Iron Load	0.96	1.17	21.88 %	0.95	-1.04 %	0.96	0.00 %
Upper 95% C.I.	1.26	1.55		1.27		1.46	
Lower 95% C.I.	0.66	0.79		0.63		0.46	
Arnot-4							
Number of Samples	81	66		43		14	
Median Acid Load	194	221	13.92 %	193	-0.52 %	185	-4.64 %
Upper 95% C.I.	232.31	263.22		233.41		248.05	
Lower 95% C.I.	155.69	178.78		152.59		121.95	
Median Iron Load	2.70	3.00	11.11 %	2.50	-7.41 %	2.60	-3.70 %
Upper 95% C.I.	3.35	3.78		3.22		3.62	
Lower 95% C.I.	2.05	2.22		1.78		1.58	
Clarion							
Number of Samples	75	53		41		28	
Median Acid Load	39.50	40.00	1.27 %	39.00	-1.27 %	40.00	1.27 %
Upper 95% C.I.	49.11	51.45		52.01		54.74	
Lower 95% C.I.	29.89	28.55		25.99		25.26	
Median Iron Load	5.51	4.26	-22.69 %	4.45	-19.24 %	7.37	33.76 %
Upper 95% C.I.	7.27	6.07		7.02		10.51	
Lower 95% C.I.	3.75	2.45		1.88		4.23	
Ernest							
Number of Samples	189	146		53		19	
Median Acid Load	1456	1682	15.52 %	2048	40.66 %	1882	29.26 %
Upper 95% C.I.	1991.91	2410.88		2923.35		3805.81	
Lower 95% C.I.	920.09	953.12		1172.65		-41.81	
Median Iron Load	229	264	15.28 %	304	32.75 %	348	51.97 %
Upper 95% C.I.	342.83	412.68		474.61		662.48	
Lower 95% C.I.	115.17	115.32		133.39		33.52	
Fisher							

Parameter	Full Data	9 Month Data	Percent Error	Monthly Samples	Percent Error	Quarterly Samples	Percent Error
Number of Samples	35	24		24		10	
Median Acid Load	72	82	13.89 %	85	18.06 %	102	41.67 %
Upper 95% C.I.	95.00	109.47		121.73		165.38	
Lower 95% C.I.	49.00	54.53		48.27		38.62	
Median Iron Load	1.4	1.4	0.00 %	1.4	0.00 %	1.4	0.00 %
Upper 95% C.I.	1.74	1.75		1.66		1.63	
Lower 95% C.I.	1.06	1.05		1.14		1.17	
Hamilton-8							
Number of Samples	109	85		52		38	
Median Acid Load	59.00	66.86	13.32 %	58.70	-0.51%	55.70	-5.59 %
Upper 95% C.I.	67.92	77.16		68.90		72.60	
Lower 95% C.I.	50.80	56.56		48.50		38.30	
Median Iron Load	2.66	3.12	17.29 %	2.63	-1.13 %	1.81	-31.95 %
Upper 95% C.I.	3.19	3.76		3.45		2.77	
Lower 95% C.I.	2.13	2.48		1.81		0.85	
Markson							
Number of Samples	98	77		30		22	
Median Acid Load	1467	1452	-1.02 %	1491	1.64 %	1546	5.39 %
Upper 95% C.I.	1575.47	1597.55		1624.02		1816.11	
Lower 95% C.I.	1358.53	1306.45		1357.98		1275.89	
Median Iron Load	408	402	-1.47 %	402	-1.47 %	402	-1.47 %
Upper 95% C.I.	430.76	428.18		428.14		434.13	
Lower 95% C.I.	385.24	375.82		375.56		369.87	
Average of All Discharges							
Median Acid Load			10.75 %		9.27 %		12.55 %
Median Iron Load			12.82 %		9.01 %		17.55 %

Table 5.1c: Comparison of Median Acidity and Iron Loads by Baseline Sampling Year

Parameter	Full Data	1980	1981	1982	1983	1984	1985
Arnot-3							
Number of Samples	82	17	21	27	15		
Median Acid Load	72.3	66.9	63.8	83.9	86.5		
Upper 95% C.I.	86.53	94.23	76.79	110.69	128.53		
Lower 95% C.I.	58.07	34.37	46.62	43.72	39.51		
Median Iron Load	0.96	0.57	0.98	1.44	1.17		
Upper 95% C.I.	1.26	0.90	1.37	2.04	2.12		
Lower 95% C.I.	0.66	0.24	0.59	0.84	0.22		
Arnot-4							
Number of Samples	81	17	20	29	15		
Median Acid Load	194	157	159	208	242		
Upper 95% C.I.	232.31	253.83	209.32	256.19	368.52		
Lower 95% C.I.	155.69	60.17	108.68	159.81	115.48		
Median Iron Load	2.7	1.5	1.6	3.0	3.0		
Upper 95% C.I.	3.35	2.95	1.76	4.11	5.20		
Lower 95% C.I.	2.05	0.05	1.44	1.89	0.80		
Clarion							
Number of Samples	75	17	20	11	16	9	
Median Acid Load	39.5	41.0	56.5	27.0	14.0	42.0	
Upper 95% C.I.	49.11	74.00	75.80	46.41	27.99	61.26	
Lower 95% C.I.	29.89	8.00	37.20	7.59	0.01	22.74	
Median Iron Load	5.51	4.13	10.78	7.65	1.66	5.69	
Upper 95% C.I.	7.27	7.19	14.49	18.00	3.13	9.68	
Lower 95% C.I.	3.75	1.07	7.07	-2.70	0.19	1.70	
Ernest							
Number of Samples	189	16	38	47	49	39	
Median Acid Load	1456	1736	615	574	5193	1697	
Upper 95% C.I.	1991.91	2742.88	1141.38	1295.70	6551.26	2906.26	
Lower 95% C.I.	920.09	729.12	88.62	-147.70	3834.74	487.74	
Median Iron Load	229	225	85	60	1069	216	
Upper 95% C.I.	342.83	327.04	169.49	142.37	1346.84	448.62	
Lower 95% C.I.	115.17	122.96	0.51	-22.37	791.16	-16.62	
Fisher							
Number of Samples	35	9	8	17	21	12	8
Median Acid Load	72	49	101	80	36	26	42
Upper 95% C.I.	95.00	86.76	202.90	119.39	45.26	41.20	60.10
Lower 95% C.I.	49.00	11.24	-0.90	40.61	26.74	10.80	23.90
Median Iron Load	1.4	1.5	2.1	1.2	0.9	0.2	0.2
Upper 95% C.I.	1.74	2.13	3.65	1.59	1.12	0.41	0.36
Lower 95% C.I.	1.06	0.87	0.55	0.81	0.68	-0.01	0.04
Hamilton-8							
Number of Samples	109	16	24	27	25	17	
Median Acid Load	59.00	56.70	69.10	37.60	54.54	77.40	
Upper 95% C.I.	67.92	79.01	87.02	60.69	71.41	91.27	

Parameter	Full Data	1980	1981	1982	1983	1984	1985
Lower 95% C.I.	50.80	34.39	51.18	14.51	37.67	63.53	
Median Iron Load	2.66	4.35	3.50	1.07	1.53	3.34	
Upper 95% C.I.	3.19	6.74	4.98	1.72	2.16	4.21	
Lower 95% C.I.	2.13	1.96	2.02	0.42	0.90	2.47	
Markson							
Number of Samples	98	15	49	34			
Median Acid Load	1467	1502	1327	1888			
Upper 95% C.I.	1575.47	1726.37	1445.08	2366.21			
Lower 95% C.I.	1358.53	1277.63	1208.92	1409.79			
Median Iron Load	408	336	403	449			
Upper 95% C.I.	430.76	406.26	423.90	512.73			
Lower 95% C.I.	385.24	265.74	382.10	385.27			

5.1.1 Sampling Interval

For net acidity loads, two (Ernest and Fisher) out of the seven discharge datasets exceeded 10 percent error when both monthly and quarterly sample intervals were used. The average error for net acidity load using monthly sample collection was 9.27 percent. The average error for net acidity load using quarterly samples was 12.55 percent. For iron loads, 10 percent error was exceeded for monthly sampling on the Clarion and Ernest discharges. Ten percent error was exceeded with quarterly sampling for the Clarion, Ernest, and Hamilton discharges. The average error for iron load was 9.01 percent for monthly samples and 17.55 percent for quarterly samples. Monthly sampling yielded results closer to the full baseline than quarterly sampling. The effect of quarterly sampling would likely be even more pronounced if a shorter sampling period (e.g., one year) had been used.

The difference in baselines calculated for each discharge using monthly samples versus quarterly samples is illustrated in Figures 5.1a through 5.1ab. These figures also present yearly comparison of baseline pollutant loadings. In the data comparison (monthly versus quarterly) figures, the short horizontal lines represent the median values. The parallel vertical lines represent the range of the 95 percent confidence intervals around the median. The left-hand line shows the 95 percent confidence interval calculated based on the actual number of samples (N) as listed in Table 5.1b. However, because each sample subset contains a different number of samples, the confidence intervals are affected by different N values. A smaller number of samples results in a wider confidence interval. For purposes of comparison between datasets, the right-hand line shows the 95 percent confidence interval based on an arbitrarily set value for N equal to 12.

Figure 5.1a: Arnot-3 Acidity Loading (1980-1981)

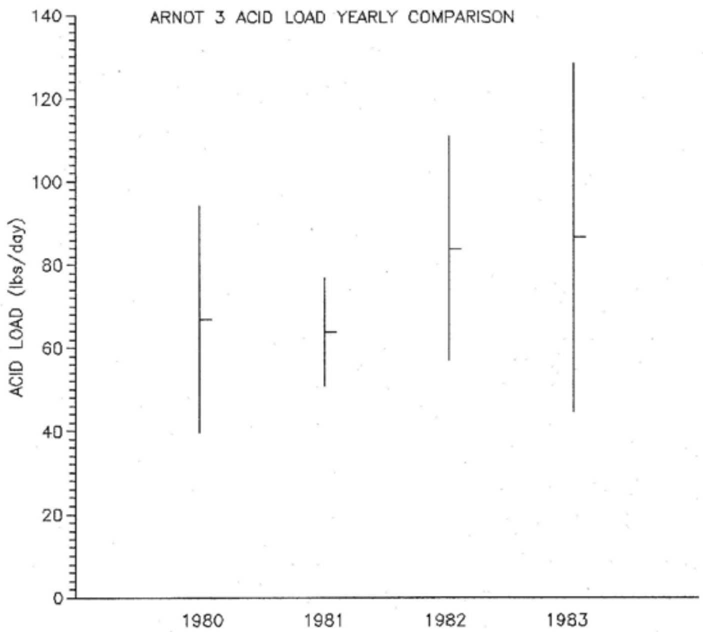


Figure 5.1b: Arnot-3 Flow Data Comparison

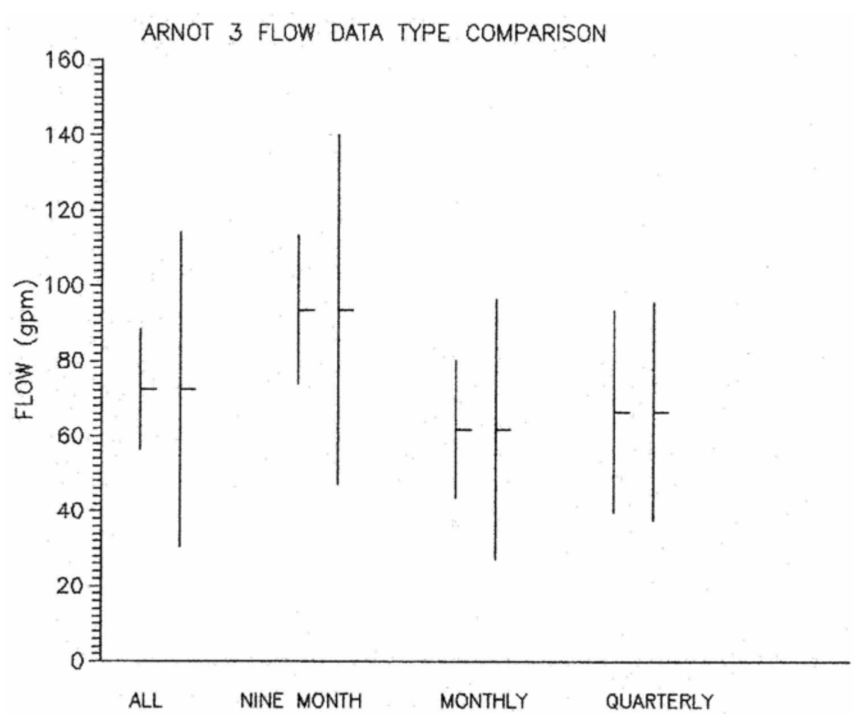


Figure 5.1c: Arnot-3 Iron Load Data Comparison

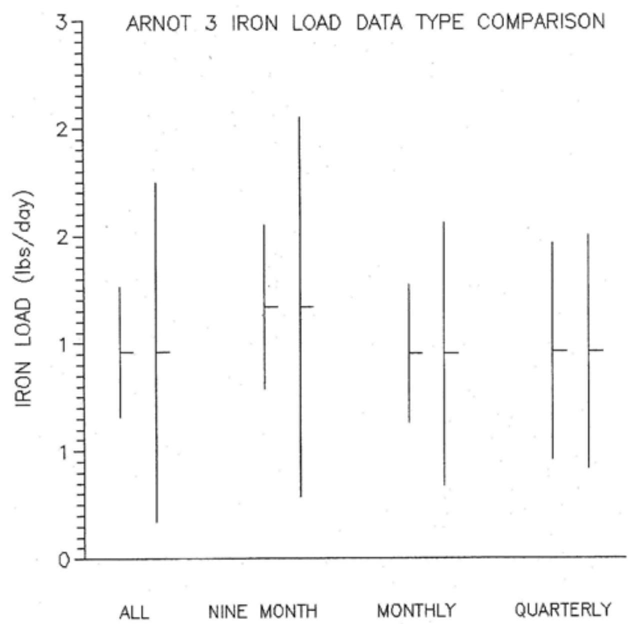


Figure 5.1d: Arnot-3 Acidity Load Data Comparison

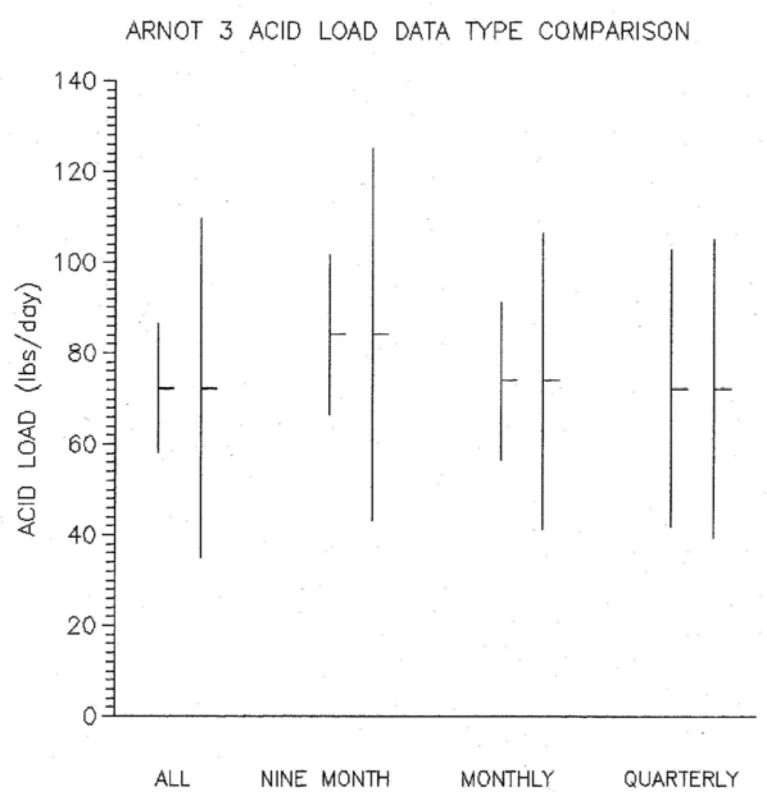


Figure 5.1e: Arnot-3 Monthly Flow Comparison

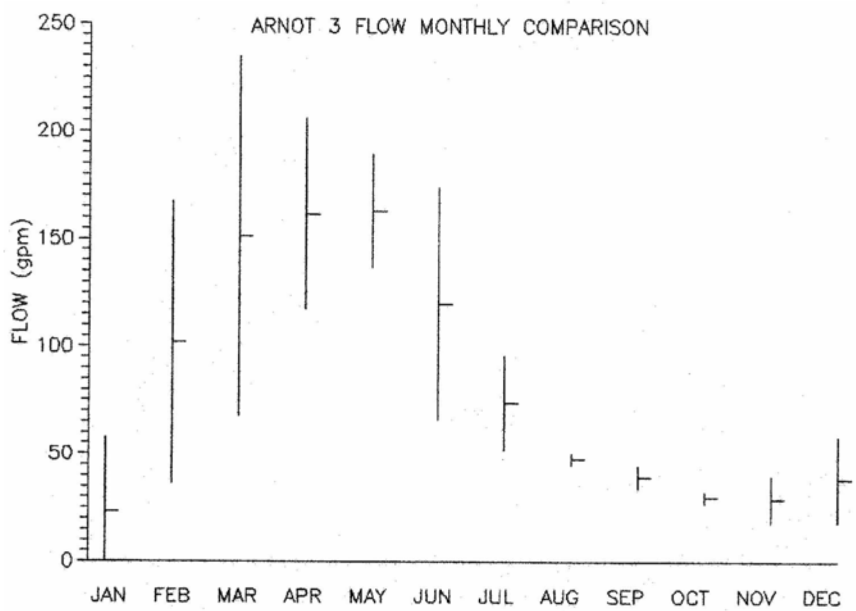


Figure 5.1f: Arnot-3 Monthly Acidity Load Comparison

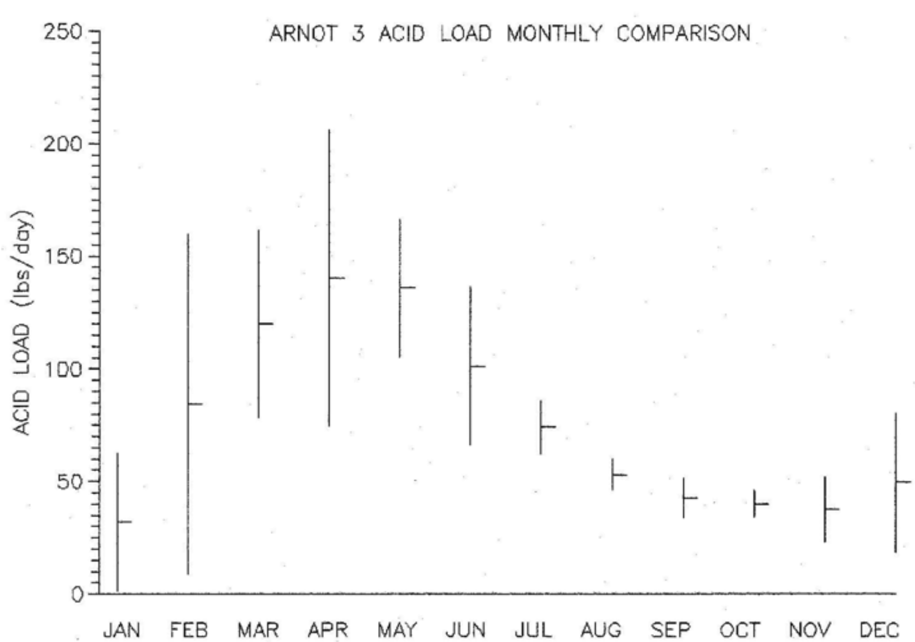


Figure 5.1g: Arnot-4 Acidity Load Data Comparison

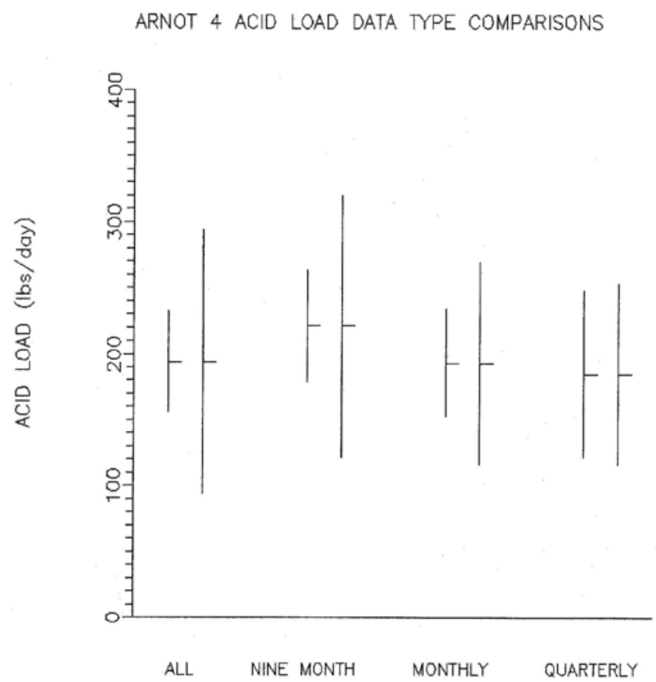


Figure 5.1h: Arnot-4 Acidity Load (1980-1983)

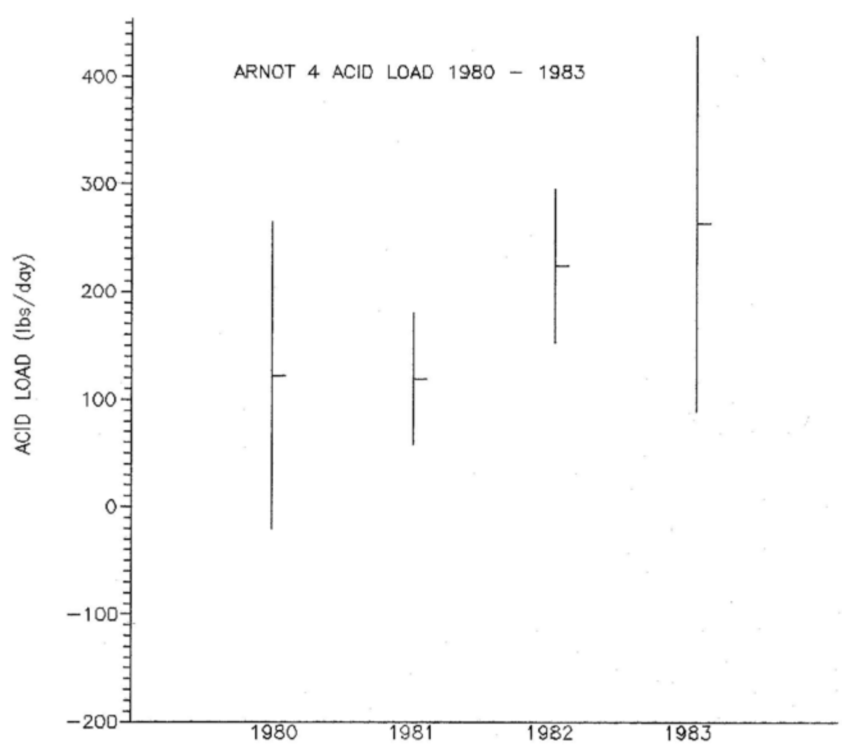


Figure 5.1i: Clarion Acidity Load Data Comparison

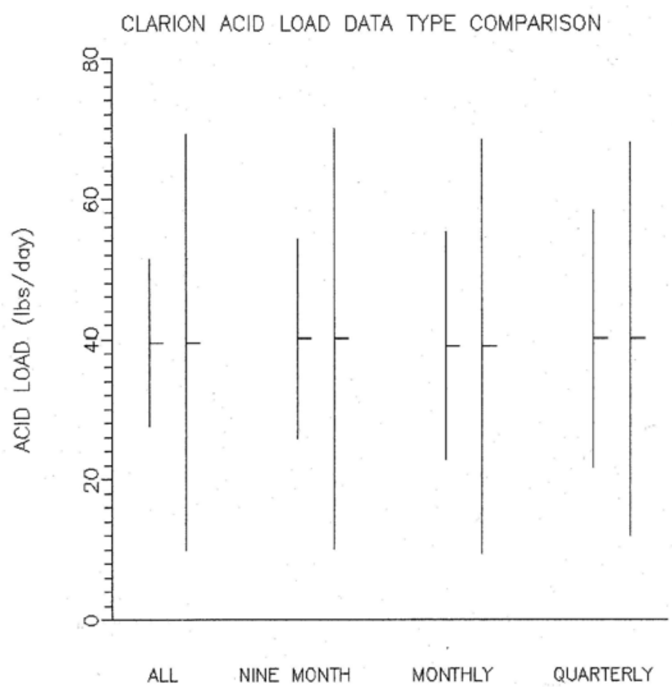


Figure 5.1j: Clarion Iron Load Data Comparison

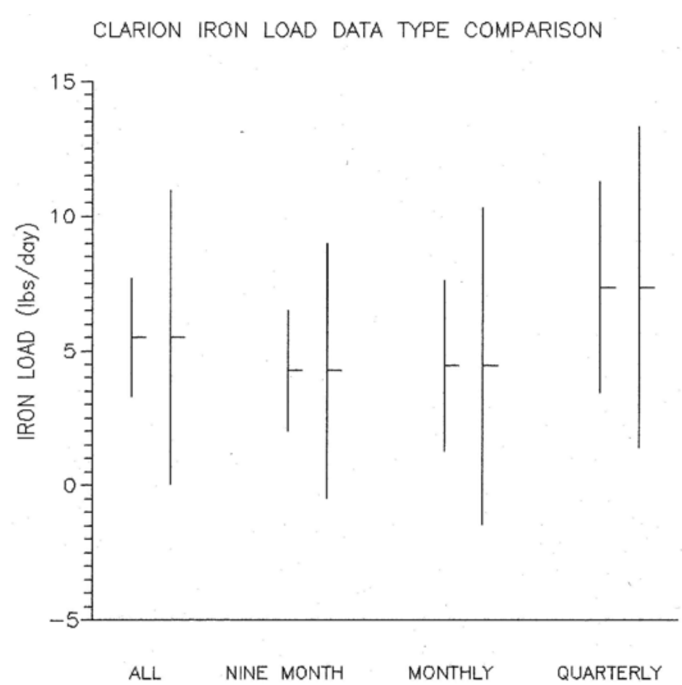


Figure 5.1k: Clarion Acidity Load (1982-1986)

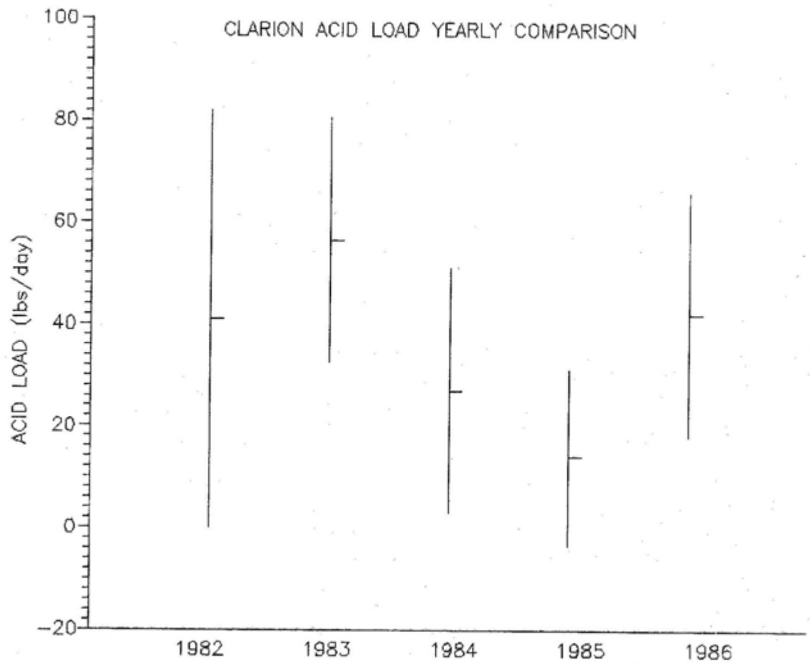


Figure 5.1l: Clarion Iron Load (1980-1983)

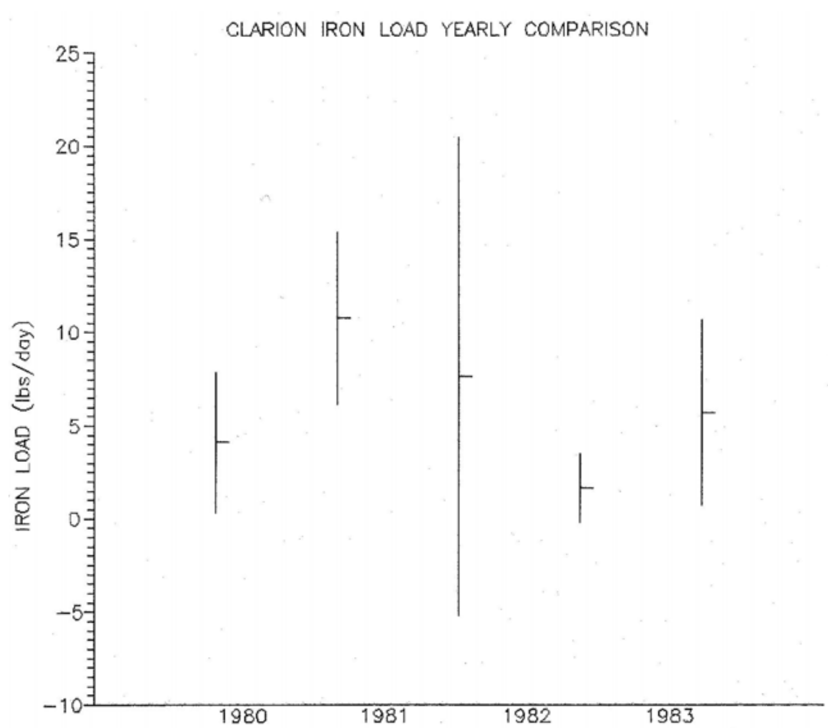


Figure 5.1m: Ernest Acidity Load Data Comparison

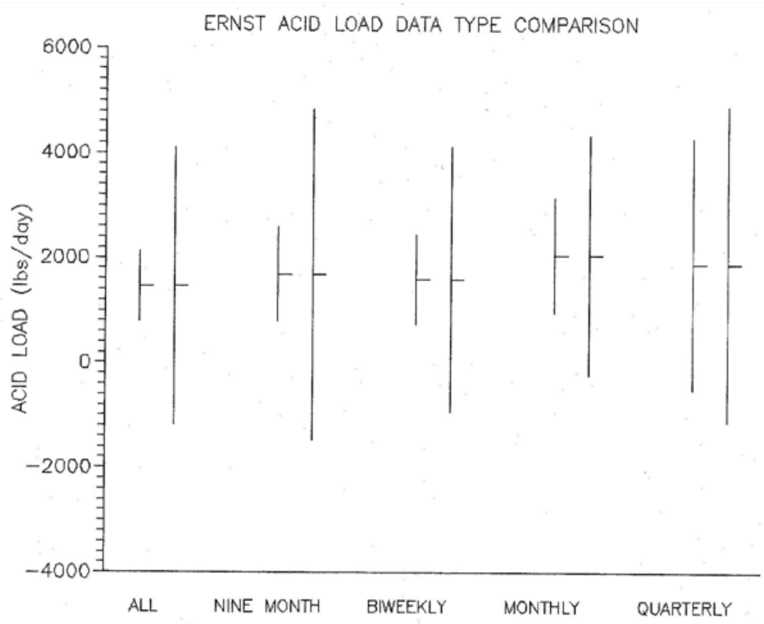


Figure 5.1n: Ernest Iron Load Data Comparison

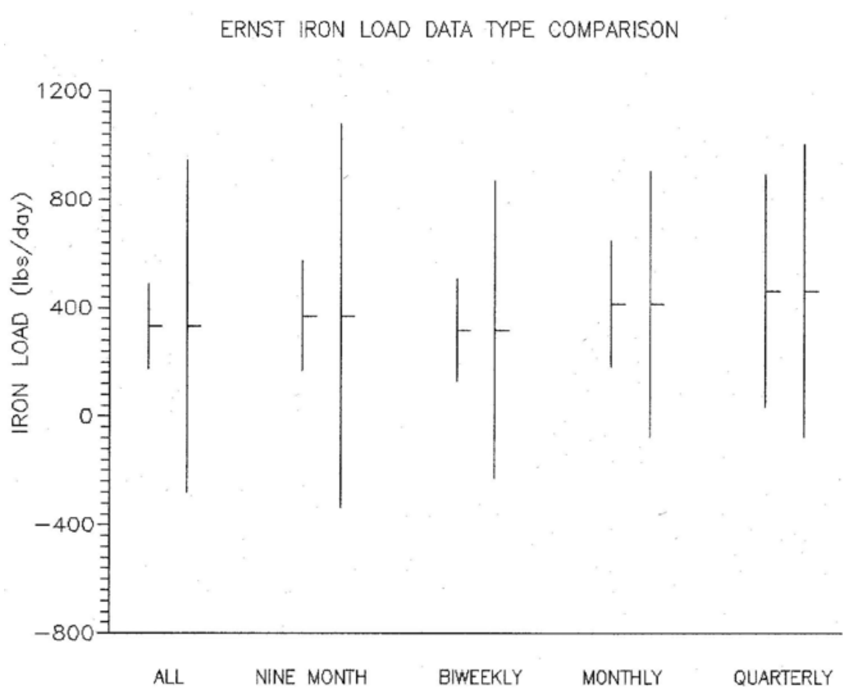


Figure 5.1o: Ernest Acidity Load Data Comparison

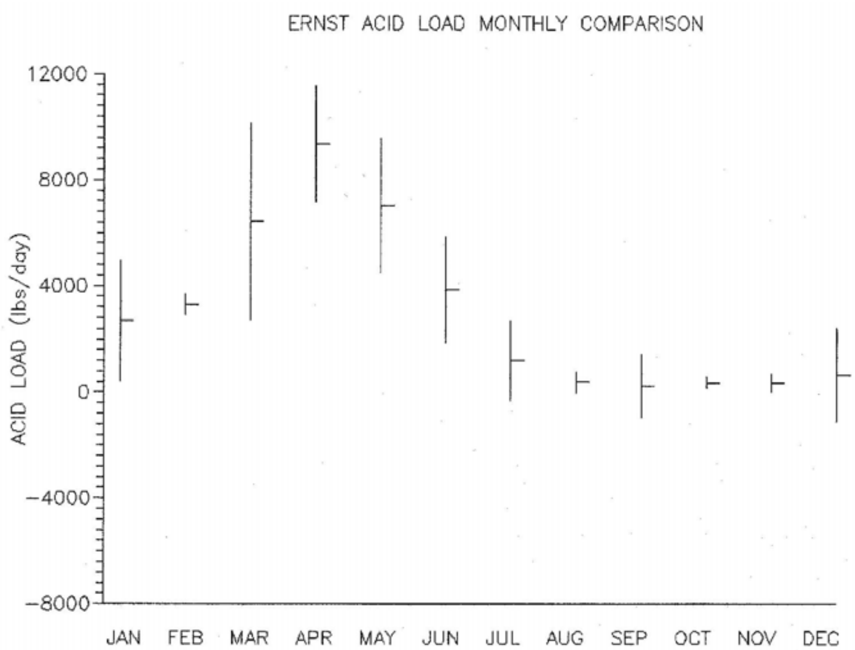


Figure 5.1p: Ernest Acidity Load (1981-1985)

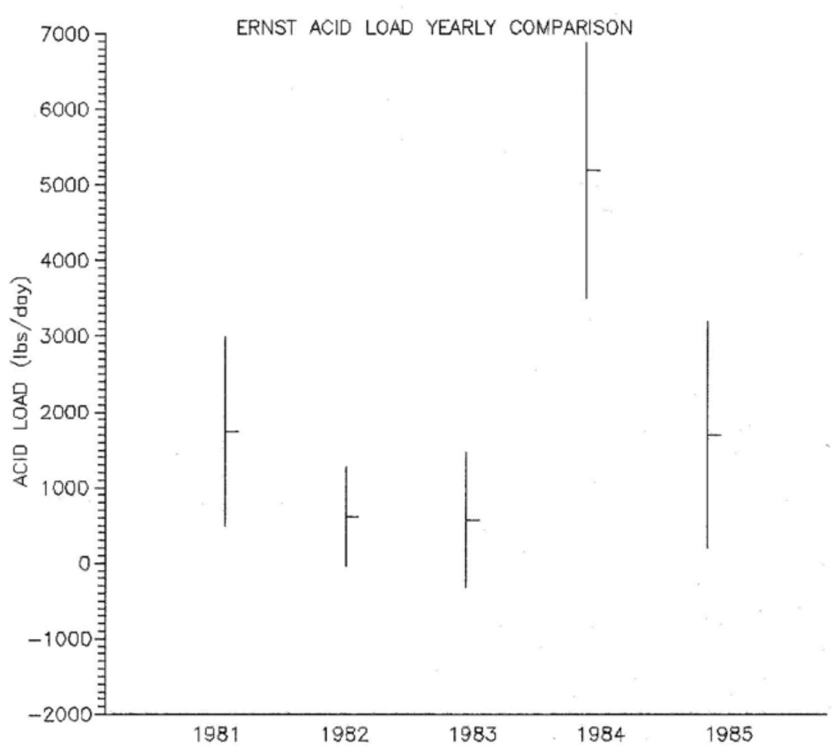


Figure 5.1q: Fisher Monthly Acidity Load

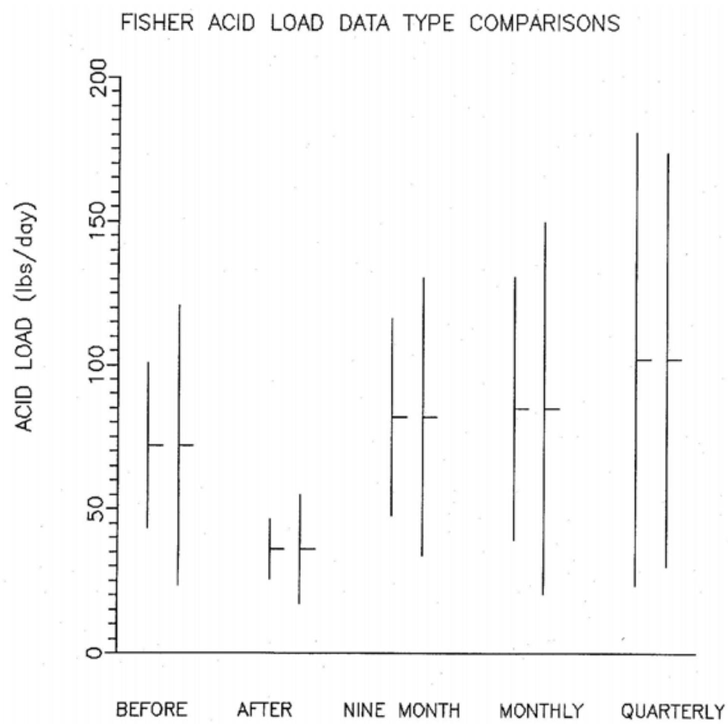


Figure 5.1r: Fisher Iron Load Data Comparison

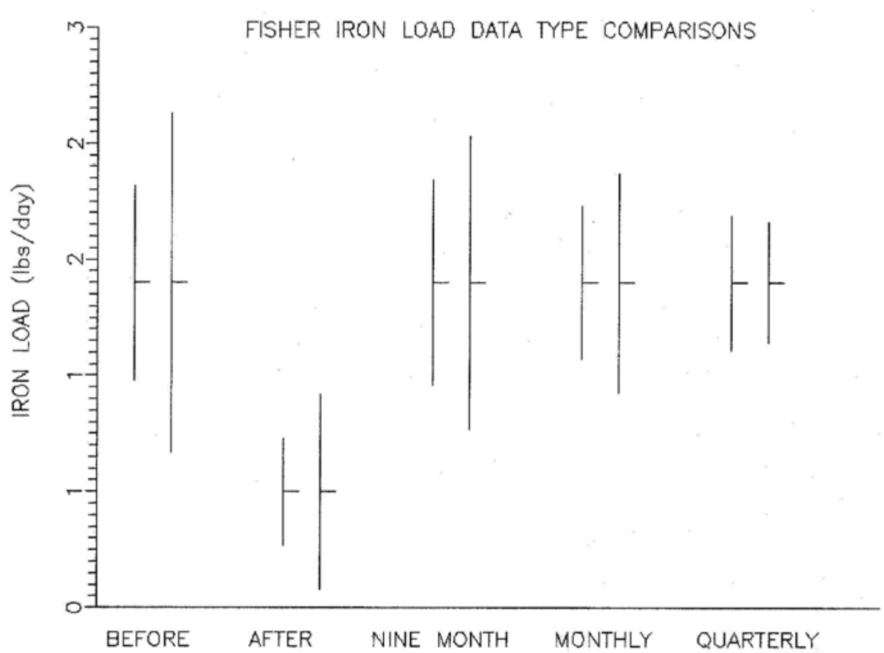


Figure 5.1s: Fisher Acidity Load Data (1982-1987)

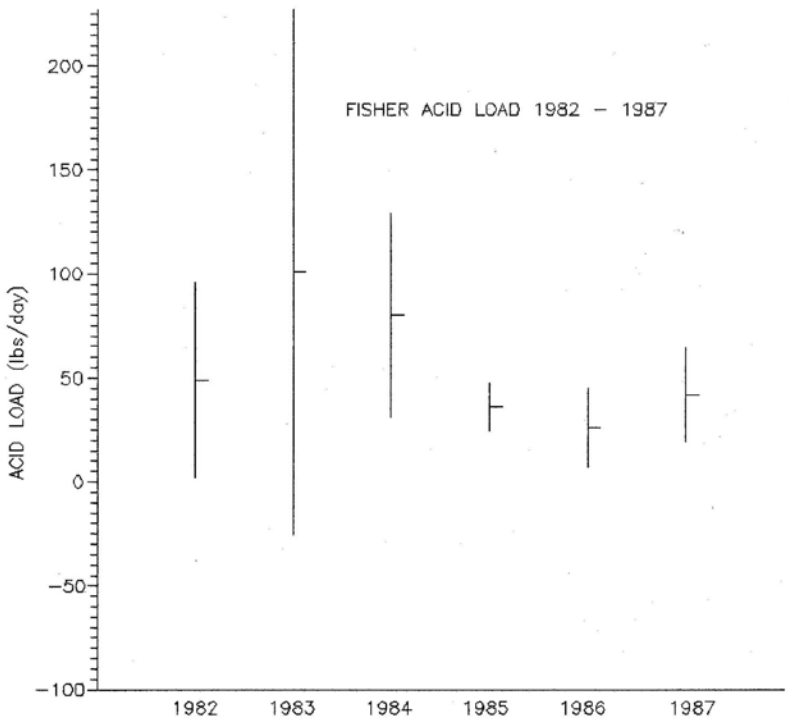


Figure 5.1t: Fisher Iron Load Data (1982-1987)

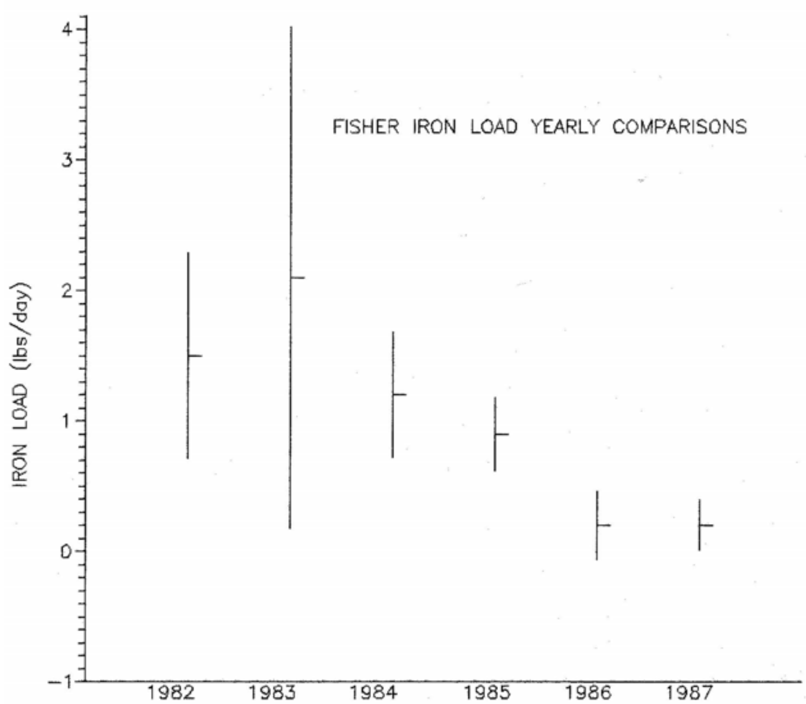


Figure 5.1u: Hamilton-8 Acidity Load Data Comparison

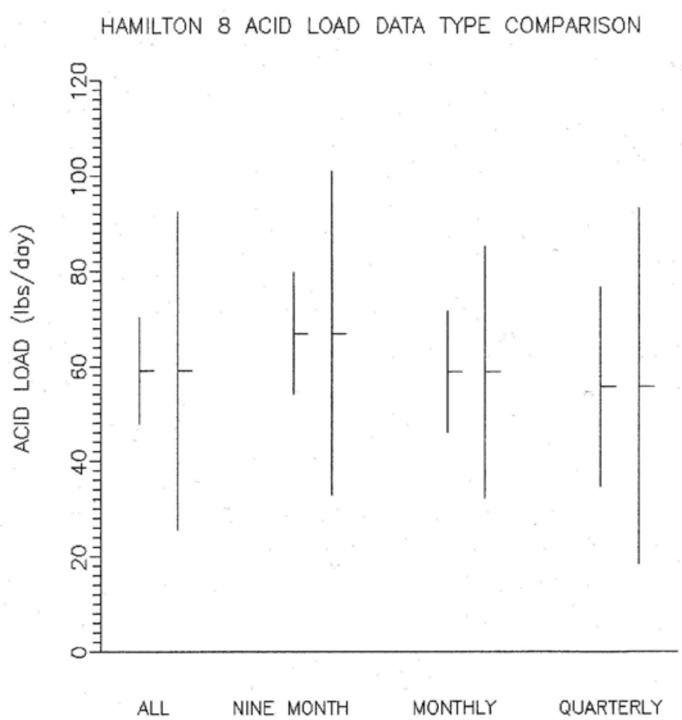


Figure 5.1v: Hamilton-8 Iron Load Data Comparison

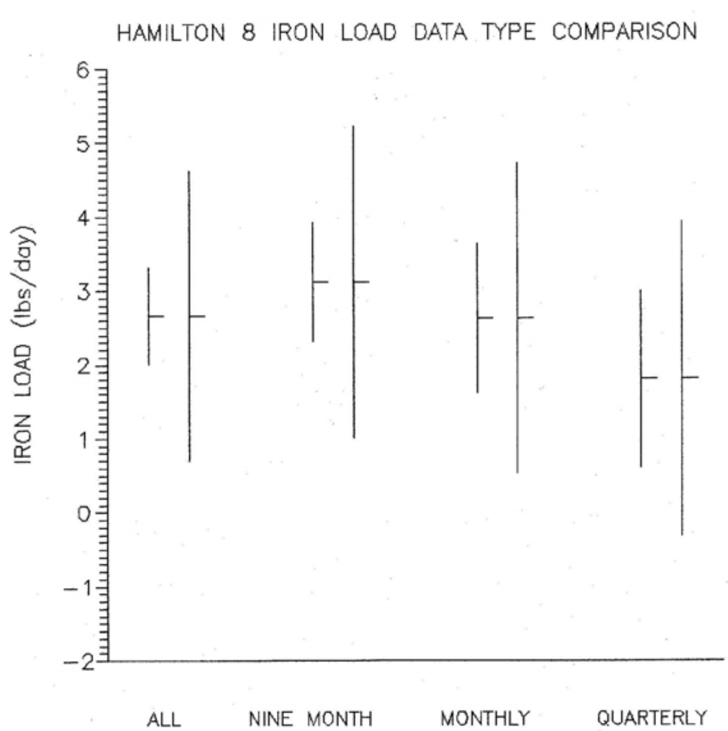


Figure 5.1w: Hamilton-8 Acidity Load (1981-1985)

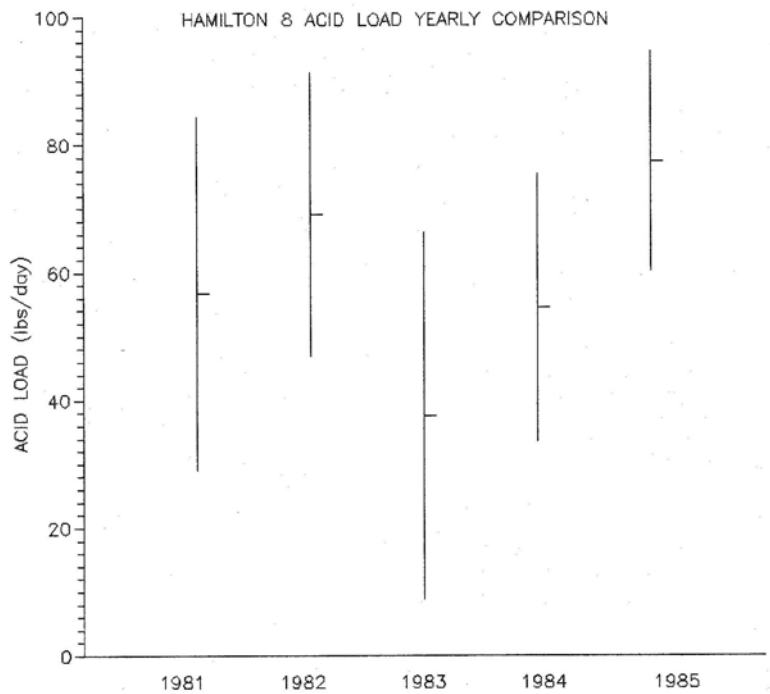


Figure 5.1x: Hamilton-8 Iron Load (1981-1985)

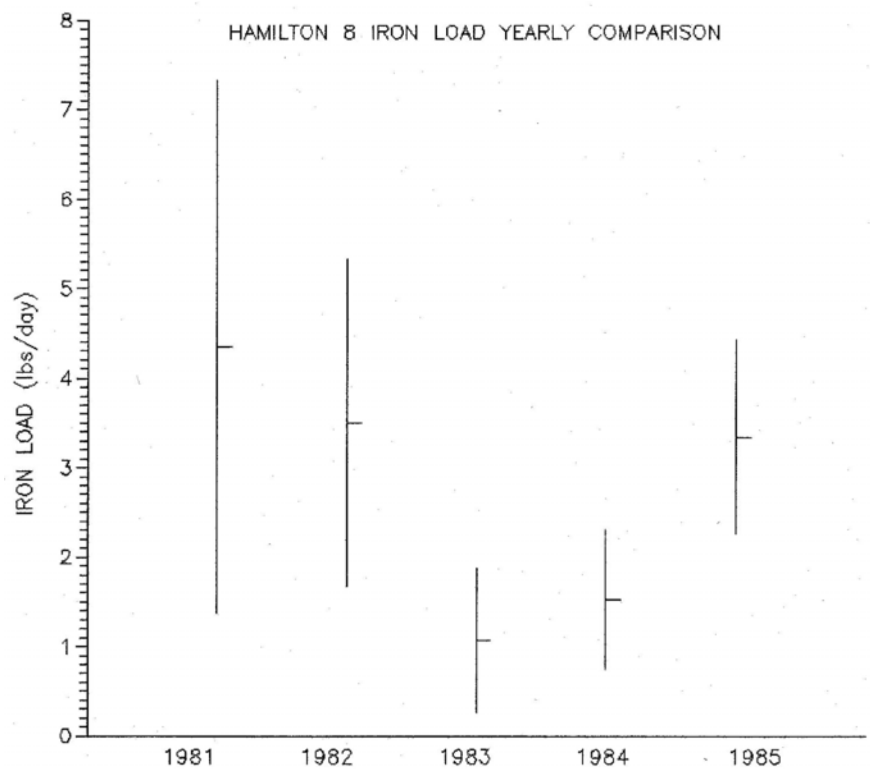


Figure 5.1y: Markson Acidity Load (1984-1986)

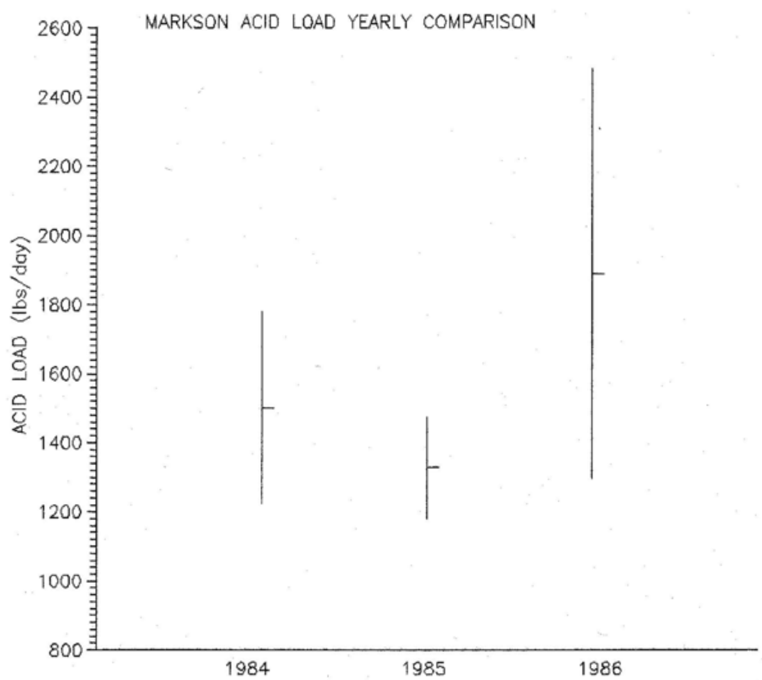


Figure 5.1z: Markson Iron Load (1984-1986)

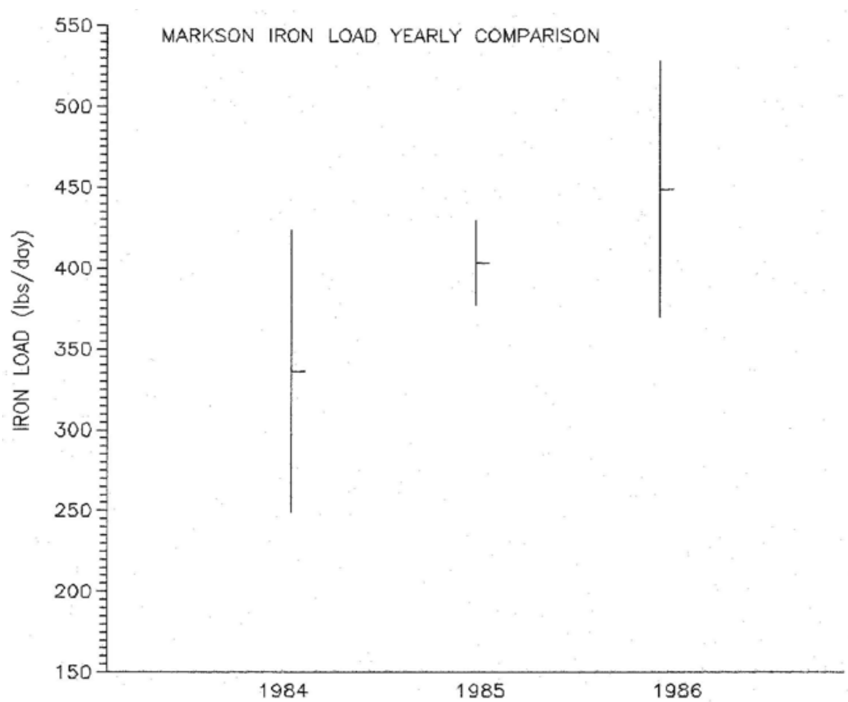


Figure 5.1aa: Acidity Load Data Comparison

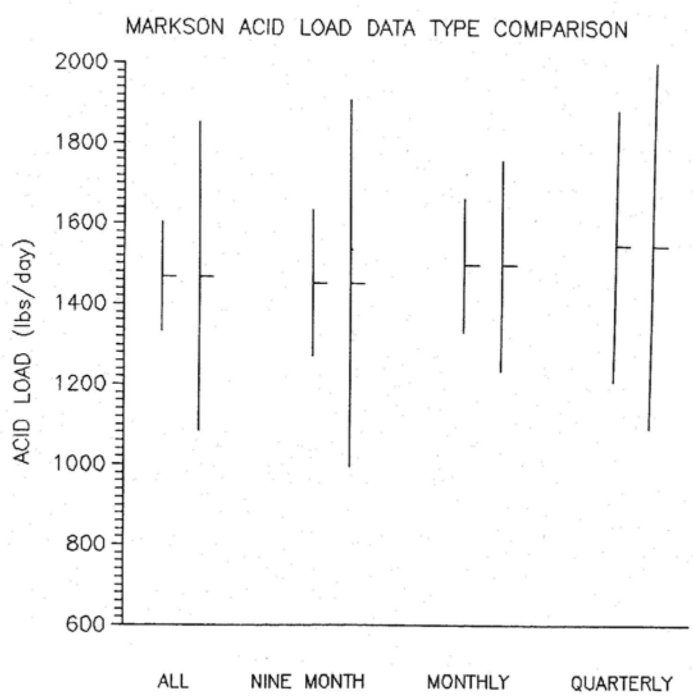
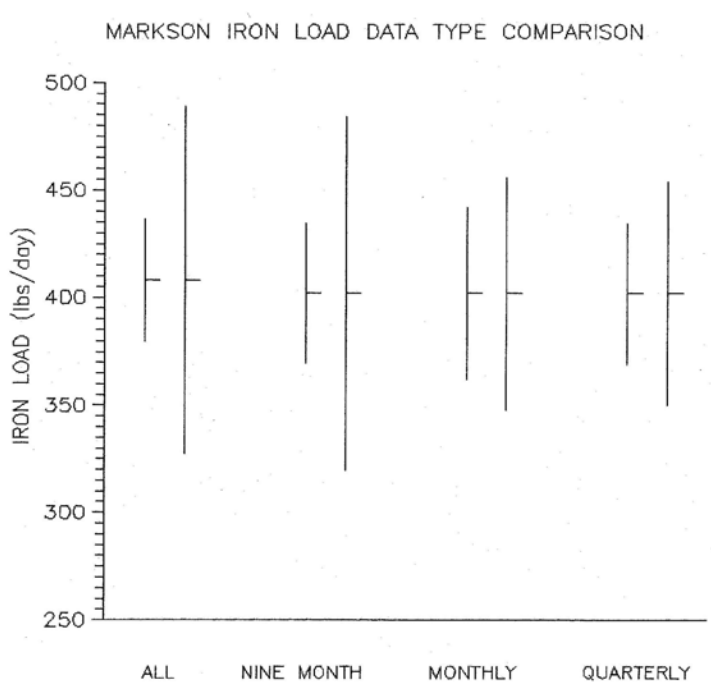


Figure 5.1ab: Markson Iron Load Data Comparison



5.1.2 Duration of Baseline Sampling

Previous study of these datasets (Griffiths, no date; 1987a-e; 1988a, b) observed that the months of November, December, and January typically exhibited behavior characteristic of median values and that extreme high and low flows and low and high concentrations were represented by the late winter/early spring and late summer/early fall months, respectively. This indicates the possibility that it may be acceptable to limit sample collection to a nine-month period that excludes the months of November, December, and January. To test this hypothesis, the long-term datasets were subsetted by eliminating all of the data from these three months, recalculating the baselines, and comparing the baseline median values for the full dataset and the nine-month subset. The results are shown in Table 5.1b.

Again using a 10 percent error criterion as a threshold for comparison, only two of the seven datasets (Clarion and Markson) showed less than 10 percent error in baseline median net acidity loads. Baseline iron loads showed similar results, with only two datasets (Fisher and Markson) showing less than 10 percent error. The average error for median acidity load was 10.75 percent. The average error for median iron load was 12.82 percent. The source of this error may be because even though the three excluded months typically have average flows, the median yearly flow may be greatly over or under estimated by excluding these months. For example, the median flow of the Arnot-3 discharge (Figure 5.1b) is much higher when using the nine-month data than with using the full 12-month dataset. Acidity loading rates, which are dominated by flows, parallel this effect (Figure 5.1d).

Based on this analysis, exclusion of the months of November, December, and January (in Pennsylvania and for areas with similar climates) poses a significant risk of not being representative of the entire water year and skewing the baseline loading rates, either higher or lower. Similarly, a sampling period of less than a full water year should be applied very cautiously before the results can be relied upon to develop a representative and statistically valid baseline.

5.1.3 Effects of Discharge Behavior on Baseline Sampling

Five of the seven discharges studied represent typical discharge behavior. These discharges exhibited relatively large seasonal fluctuations in flow rates with pollutant concentrations inversely proportional to flow. However, because changes in flow tend to be much greater than corresponding changes in concentration, flow tends to be the dominant factor in determining pollutant loading in these discharges. The result is a flow-dominated system with pollution loading rates that tend to closely follow the flow rate, although perhaps in a damped manner. This typical behavior is illustrated by the monthly flow and loading data from the Arnot-3 discharge (Figures 5.1e and 5.1f).

The remaining two discharges, Ernest and Markson, reacted very differently to changes in the baseline sampling period and interval. The Ernest discharge (a "slug response" discharge), yielded large percent errors for virtually every data subset. This discharge varied greatly in flow rate, concentration, and load, and responded very quickly to recharge events. These variations make representative monitoring very difficult. A baseline monitoring sampling interval that is too long (e.g., greater than monthly), can easily cause extreme events to be missed, or can over-represent extreme events if one happens to be sampled. Therefore, where this type of discharge behavior is evident, it would be prudent to use a shorter sampling interval (e.g., at least monthly) and/or expand the baseline sampling period.

The Markson discharge was the least affected by increasing the sample interval or using only nine months of data. Percent errors were relatively low regardless of the data subset used. This suggests that for discharges with typical steady-response behavior, it may be possible to obtain a suitable baseline using less frequent and possibly shorter sampling intervals. However, examination of the data on a year-by-year basis (Table 5.1c) indicates reason for caution. High volume discharges with very large storage reservoirs may be the most vulnerable to slow, long-term changes in flow caused by long-term or yearly variations in precipitation.

5.1.4 Year-to Year Variability

Annual median pollution loads and 95 percent confidence intervals for each of the seven discharges studied are presented in Table 5.1c. Although virtually all of the discharges showed some variability in confidence intervals from year-to-year, most of this variability was not statistically significant. There was only one discharge which exhibited statistically significant differences in baseline loading. The Ernest discharge, which has "slug response" behavior, tends to show extreme variability in both flow rate and load. As illustrated in Figure 5.1p, this was particularly the case in 1984, when the median acidity load was in excess of 5,000 lbs/day. This median is in contrast to all other years which had median acidity loads less than 2,000 lbs/day.

5.2 The Effects of Natural Seasonal Variations and Mining Induced Changes in Long-term Monitoring Data

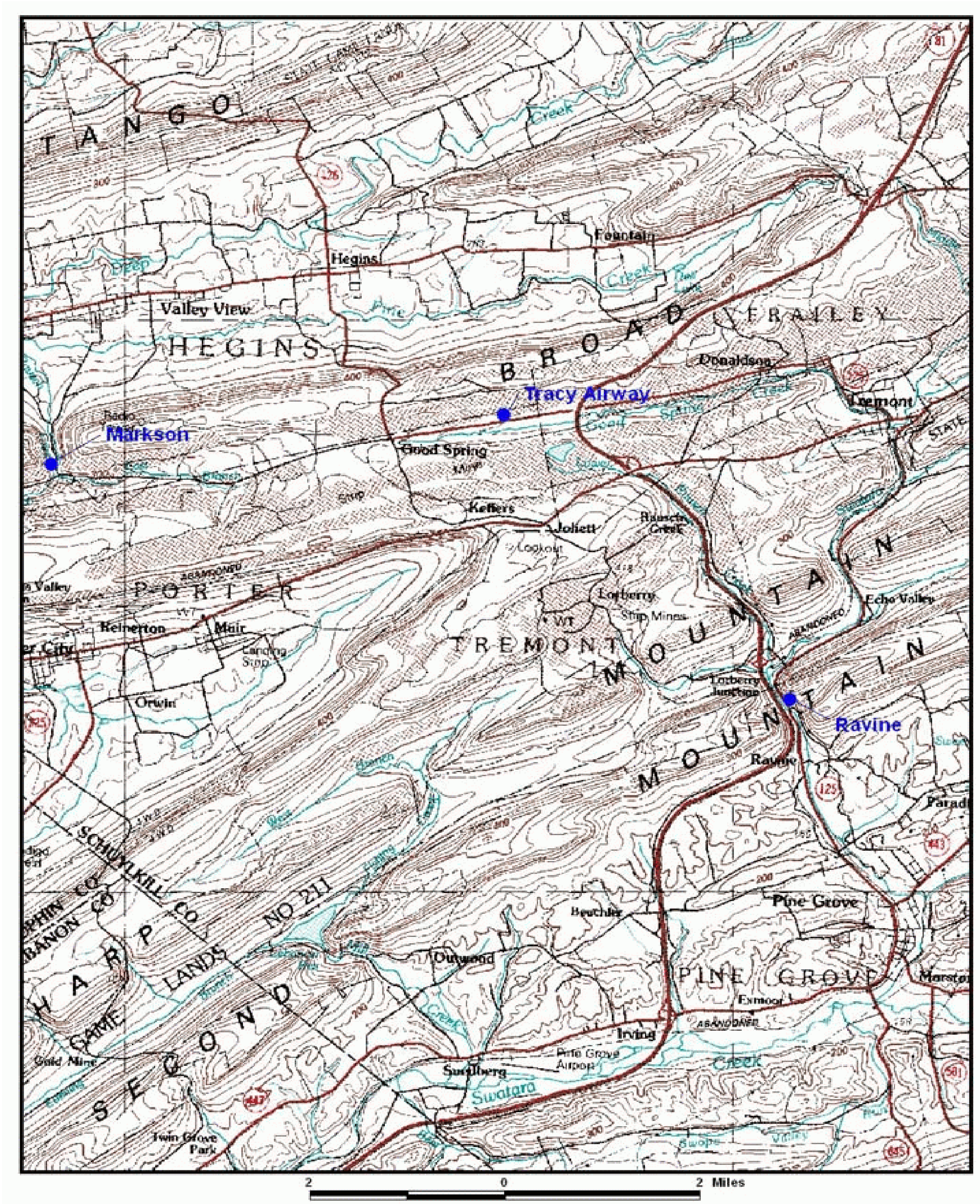
A primary reason for establishing a baseline pollution load prior to remining is to distinguish between natural seasonal variations and mining-induced changes in flow and water quality that may occur during remining and following reclamation. The reasons for using a sufficient number of samples, an adequate duration of sampling, and an acceptable sampling interval for establishing baseline pollution load are discussed throughout this document, and in EPA's Statistical Analysis of Abandoned Mine Drainage in the Establishment of the Baseline Pollution Load for Coal Remining Permits (USEPA, 2001; EPA-821-B-01-014).

The purpose of Section 5.2 is to: (1) depict the magnitude of natural seasonal variations of flow and water quality in several large abandoned underground mine discharges that were closely monitored for numerous years, and (2) provide examples of significant mining-induced changes in baseline pollution load at remining sites in Pennsylvania. Abandoned underground mine discharges (Markson, Tracy Airway, and Jeddo Tunnel) from the Pennsylvania Anthracite Coal Region are used to demonstrate the magnitude and patterns of natural seasonal variations. These discharges have been equipped with continuous flow recorders, and water quality analysis (at monthly or lesser sampling intervals) is available.

The Markson discharge is located approximately 1.2 miles (2 km) upstream from the Rausch Creek Treatment Plant operated by PA DEP and Schuylkill County (Figure 5.2a). This discharge emanates from an airway of an abandoned colliery at an elevation of 865 feet, and is a principal contributor to the acid load treated at the Rausch Creek Treatment Plant. The Tracy Airway discharge from another abandoned colliery is located 5.1 miles (8.3 km) east of the Markson discharge, and emanates from a mine-pool at an elevation of 1153 feet. The Tracy Airway discharge accounts for the largest iron load of all mine drainage discharges within the Swatara Creek watershed. The extensive data that were collected for both Markson and Tracy (Section 5.2.2) discharges is not typical of remining operations. These data were collected as the result of interest in diverting the discharges to a nearby treatment facility.

The U.S. Geological Survey (USGS) operates several gauging stations within the Swatara Creek Watershed as part of an EPA Section 319 National Monitoring Program (NMP) Project (the first of these projects in the United States focused on coal mine drainage problems) in cooperation with PA DEP, Schuylkill County, and other cooperators. The USGS station at Ravine shown in Figure 5.2a is the principal downstream gauge of the NMP project and is equipped with continuous flow and water quality recorders. The Markson discharge, Tracy discharge, and Ravine Station are located within a 5 mile radius, and therefore, should have been subjected to nearly equivalent amounts of precipitation, and duration and intensity of storm events during the period of record.

Figure 5.2a: Mine Discharge Map



5.2.1 Markson Discharge

The Markson discharge is characterized as a "steady response" type of discharge, where flow rate may vary seasonally, but changes in acidity concentrations or other water quality parameters are minimal or damped (Smith, 1988; Hornberger et al., 1990; and Brady, 1998). In a 1988 study of Markson data containing approximately 100 samples collected at weekly intervals from 1984 to 1986, Griffiths (1988a) found a lack of wide variation in all variables except flow, and found a lack of any strong relationship between pairs of variables (e.g., flow and acidity) except for an inverse correlation between iron and flow.

Monthly and annual variations in flow and concentrations of sulfate, acidity, pH, iron, and manganese are shown for an eight year period (1992-1999) in Figure 5.2b. The data were plotted on a logarithmic scale to demonstrate the range of variations in all of these variables on a single plot. Large annual variations in flow are apparent and appear to be inversely related to variations in sulfate and iron concentrations. Variations in acidity and manganese concentrations are more subtle, and do not readily show a strong relationship to flow variations.

Figure 5.2c depicts the relationships between the same flow and sulfate concentration data for the Markson discharge plotted on linear scales, while Figure 5.2d depicts the relationships between the flow and acid concentration on linear scales. Both Figures 5.2c and 5.2d show a generally strong inverse relationship between flow and pollutant concentration.

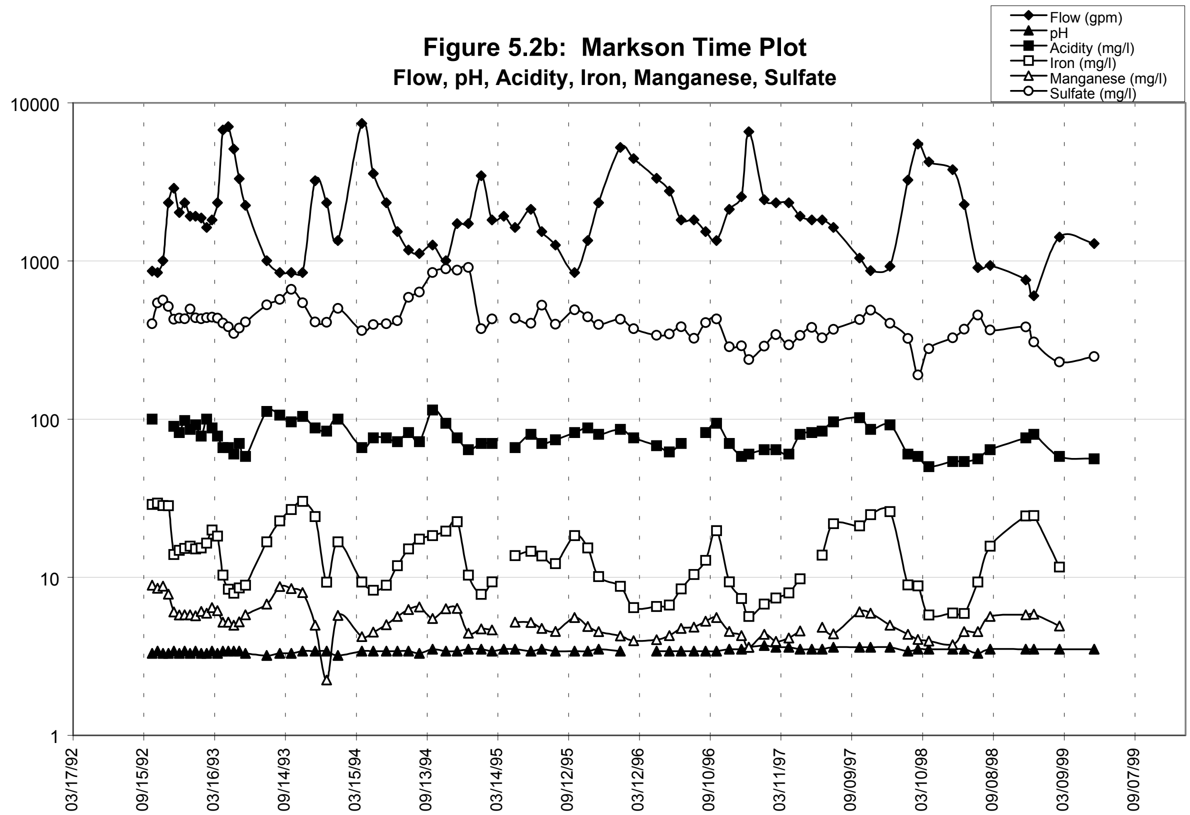


Figure 5.2b: Markson Time Plot
Flow, pH, Acidity, Iron, Manganese, Sulfate
Flow (gpm)
pH
Acidity (mg/l)
Iron (mg/l)
Manganese (mg/l)
Sulfate (mg/l)
10000
1000
100
10
1
03/17/92
09/15/92
03/16/93
09/14/93
03/15/94
09/13/94
03/14/95
09/12/95
03/12/96
09/10/96
03/11/97
09/09/97
03/10/98
09/08/98
03/09/99
09/07/99

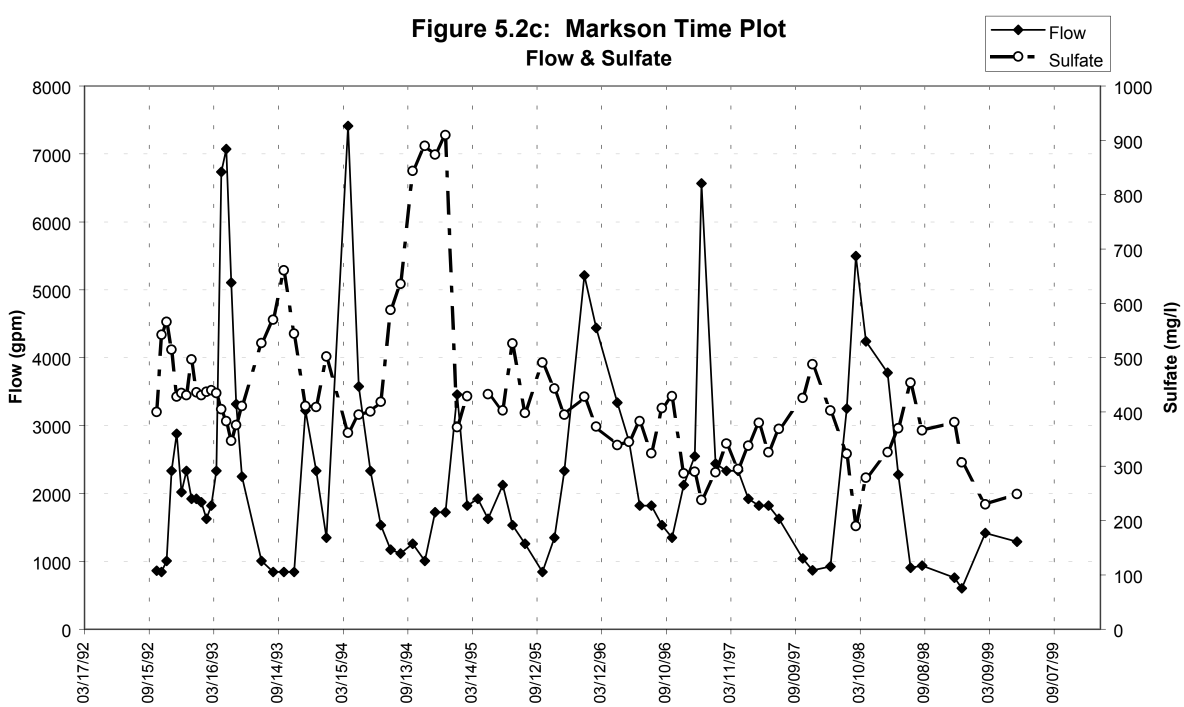


Figure 5.2c: Markson Time Plot
Flow & Sulfate
Flow
Sulfate
Flow (gpm)
Sulfate (mg/l)
8000
7000
6000
5000
4000
3000
2000
1000
0
1000
900
800
700
600
500
400
300
200
100
0
03/17/92
09/15/92
03/16/93
09/14/93
03/15/94
09/13/94
03/14/95
09/12/95
03/12/96
09/10/96
03/11/97
09/09/97
03/10/98
09/08/98
03/09/99
09/07/99

Figure 5.2d: Markson Time Plot
Flow & Acidity

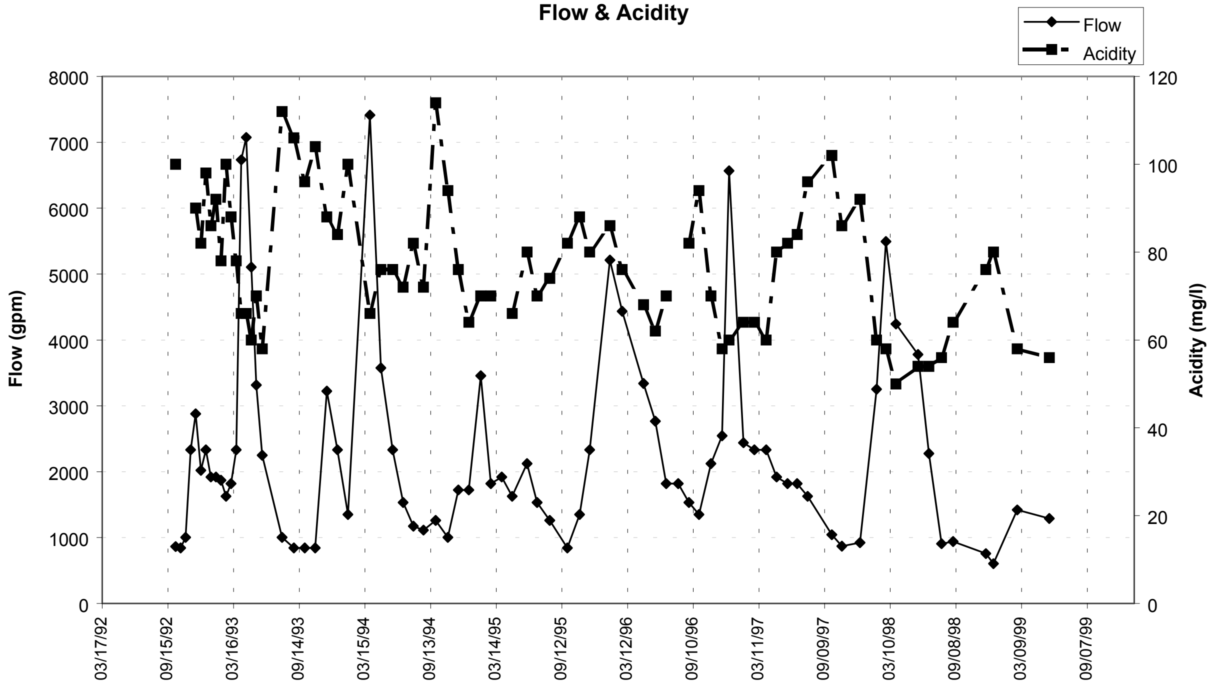


Figure 5.2e shows the relationship between monthly flow measurements and iron concentration. Figure 5.2f shows the corresponding relationships between flow and manganese concentration on linear scales. Both of these figures indicate a general inverse relationship between flow and metals concentrations in the Markson discharge. On a logarithmic scale (Figure 5.2b), manganese concentration did not appear to vary substantially in response to flow variations. This can be attributed to the relatively small range in manganese concentrations (2.2 to 8.9 mg/L) as compared to the range in iron concentrations (5.6 to 30.2 mg/L).

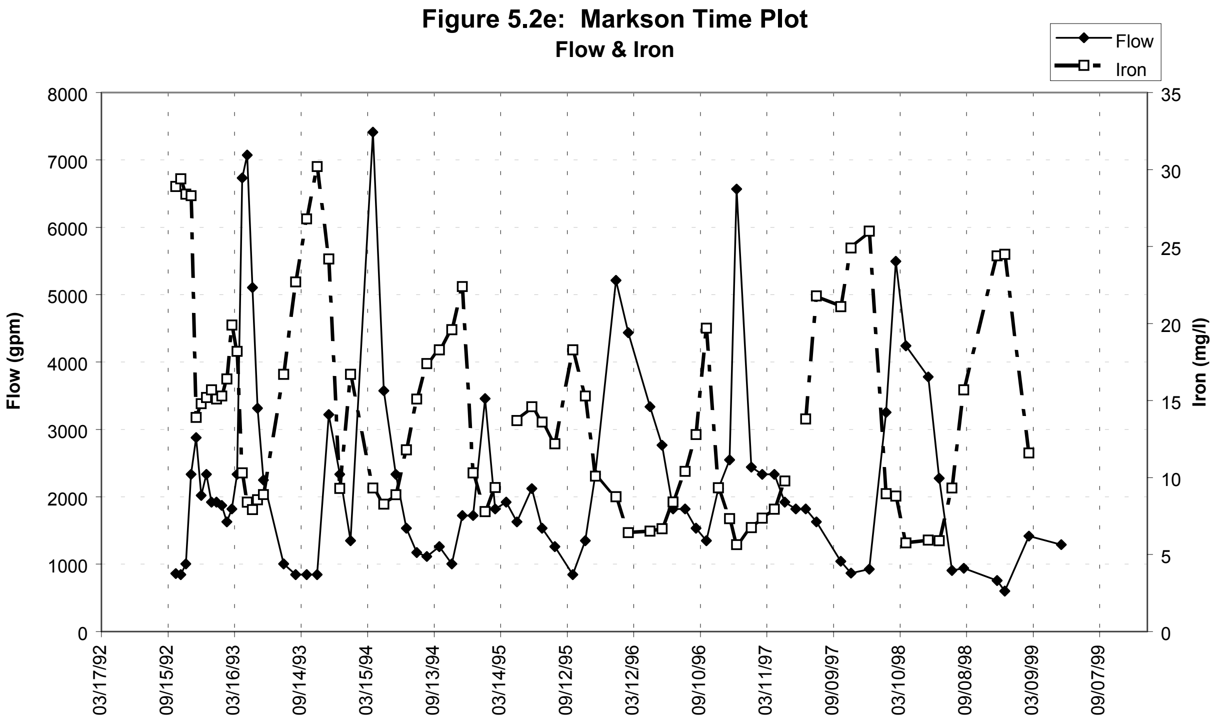


Figure 5.2e: Markson Time Plot
Flow & Iron
Flow
Iron
Flow (gpm)
Iron (mg/l)
0
1000
2000
3000
4000
5000
6000
7000
8000
0
5
10
15
20
25
30
35
03/17/92
09/15/92
03/16/93
09/14/93
03/15/94
09/13/94
03/14/95
09/12/95
03/12/96
09/10/96
03/11/97
09/09/97
03/10/98
09/08/98
03/09/99
09/07/99

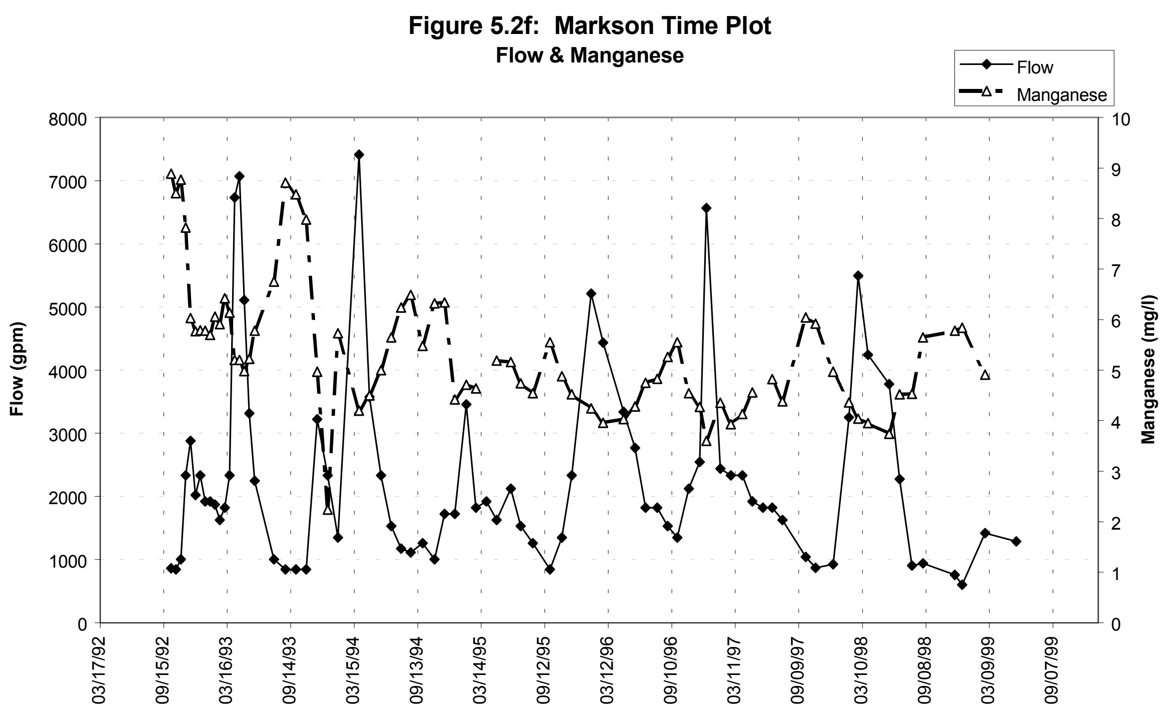
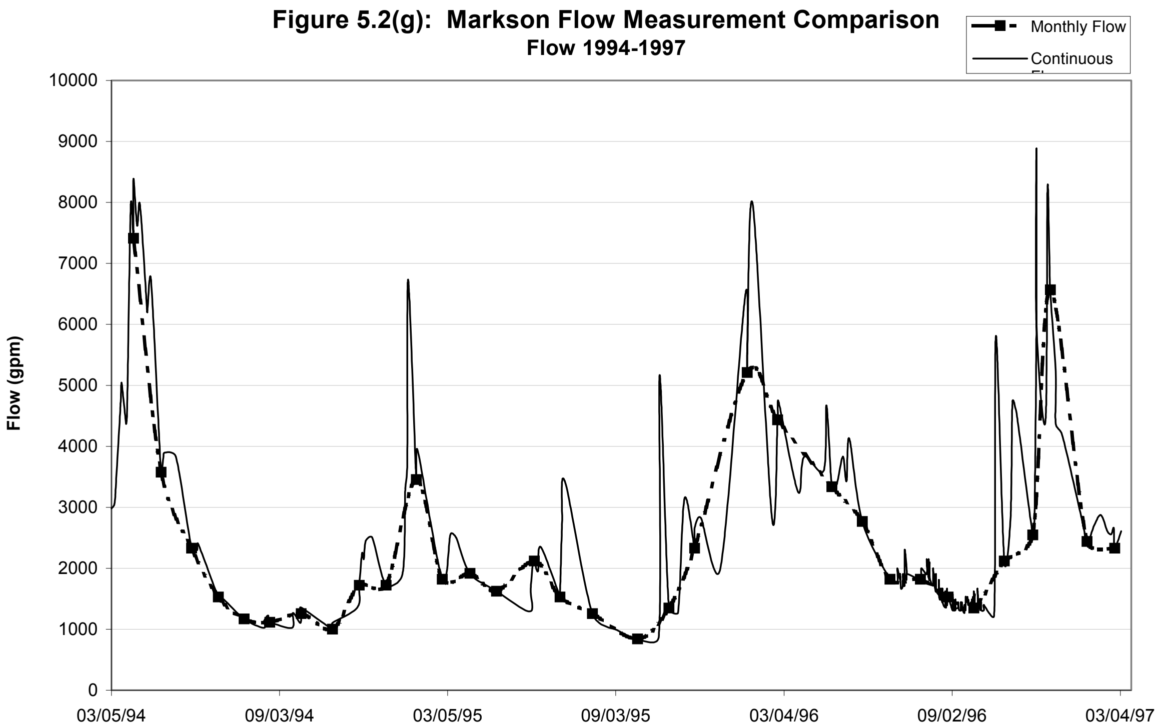


Figure 5.2f: Markson Time Plot
Flow & Manganese
Flow
Manganese
Flow (gpm)
Manganese (mg/l)
0
1000
2000
3000
4000
5000
6000
7000
8000
0
1
2
3
4
5
6
7
8
9
10
03/17/92
09/15/92
03/16/93
09/14/93
03/15/94
09/13/94
03/14/95
09/12/95
03/12/96
09/10/96
03/11/97
09/09/97
03/10/98
09/08/98
03/09/99
09/07/99

In comparing the monthly measurements of flow for the eight year period shown in Figures 5.2b, 5.2c, and 5.2d, the following observations of annual variations can be made:

- There is a fairly regular annual pattern (the highest flow generally occurring in early to mid-March and the lowest flow generally occurring in mid to late September).
- Additional yearly peaks may occur (e.g., January 1996 and September 1999).
- The highest recorded monthly flow within water years can vary significantly (from a low of 3,500 gallons per minute in 1995 to a high of 7,500 gallons per minute in 1994).
- The lowest recorded monthly flow measurements are similar (ranging from 600 to 900 gallons per minute).
- The duration of high flow periods can vary substantially (e.g., 1996 compared to 1995).

The flow measurements presented in Figures 5.2b, 5.2c, and 5.2d represent the instantaneous flow recorded at the time monthly grab samples were collected for water quality analysis. Figure 5.2g shows the full range of continuous flow measurements for the three year period from March 1994 to March 1997, compared to the plot of the monthly data used in Figures 5.2b, 5.2c, and 5.2d. In compiling the continuous flow data, all of the continuous flow gauge recorder charts were evaluated to best define the extremes and duration of high and low flow events.



In comparing the continuous flow line to the instantaneous monthly flows, the following observations can be made:

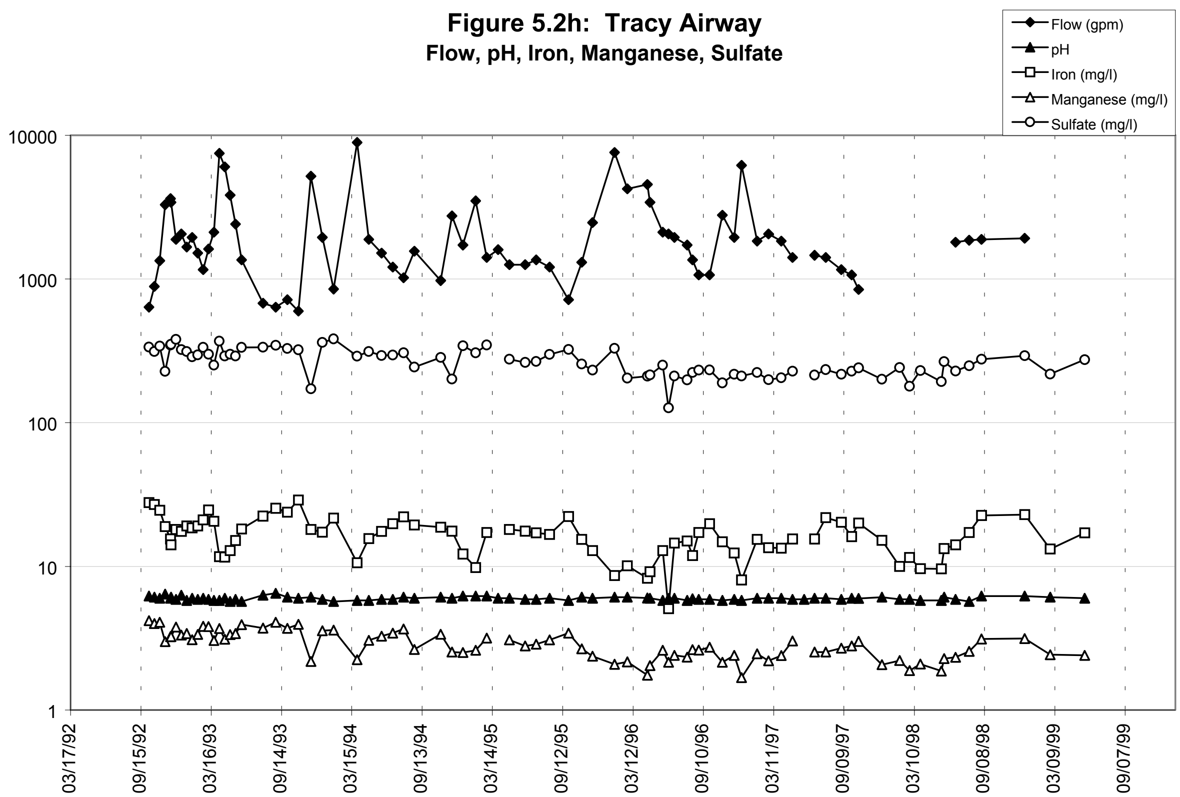
- Continuous flow measurements exhibit much more variability than instantaneous monthly flow measurements.
- Monthly measurements missed some major storm events (July 1995, October 1995, October 1996, and November 1996).
- Although the highest annual continuous flow measurement usually corresponded to the same month as the highest annual monthly measurement, the differences between these measurements were very large (3,500 to 6,700 for 1995; 5,300 to 8,100 for 1996; and 6,600 to 8,900 for 1997).
- Monthly flow measurement may have occurred somewhat after the peak of a high flow event (February 1995) or somewhat before the peak (January 1996). This may explain most of the variations mentioned in the previous item.

- The differences between low flow events on the continuous flow plot and on the instantaneous monthly flow plots are relatively small for these three water years. This may imply that it is probably not difficult to define low flow periods with monthly samples.

5.2.2 Tracy Discharge

Monthly and annual variations in discharge flow and concentrations of sulfate, acidity, pH, iron, and manganese in the Tracy Airway discharge for the eight year period for 1992 through 1999 are shown in Figure 5.2h.

Figure 5.2h: Tracy Airway
Flow, pH, Iron, Manganese, Sulfate



The range and patterns of annual and long-term variations in flow and in concentrations of sulfate, iron, and manganese concentrations are similar to those for the same variables for the Markson discharge (Figure 5.2b). However, the water quality characteristics are fundamentally different in terms of pH, acidity, and alkalinity. The pH of the Tracy discharge ranged between 5.7 and 6.5 during the eight year period, and generally had an alkalinity concentration exceeding that of acidity. The pH of the Markson discharge ranged between 3.2 and 3.7 during the eight year period, had no net alkalinity (i.e., its pH is less than the titration end point), and generally had acidity concentrations around 100 mg/L. These distinct chemical differences in two discharges, emanating from similar mines in the same geologic structure and coal seam (the Donaldson Syncline), are attributable to stratification of large and deep anthracite minepools. The Tracy discharge is a "top-water" discharge from a relatively shallow groundwater flow system (at an elevation of 1153 feet), while the Markson discharge emanates from "bottom water" at a much lower elevation in the minepool (865 feet). The chemistry of stratified anthracite mine-pools is described by Brady et al. (1998) and Barnes et al. (1964). However, these discharges are similar in the relationship of flow and water quality to natural seasonal variations.

The monthly flow pattern of the Tracy discharge (Figure 5.2h) is very similar to that of the Markson discharge (Figure 5.2b), except the Tracy discharge flows appear to be somewhat more variable or peaked. When the annual patterns of high and low flows are compared, the Tracy discharge has two flow peaks (November 1995 and October 1996) that do not occur for the Markson discharge. These two peaks indicate storm events undetected by monthly sampling. The plot of continuous and monthly flow records for the Tracy discharge (Figure 5.2i) reveals that the Tracy discharge was sampled a short time before the November 1995 flow peak and well after the flow peak for October 1996 (continuous flow peak equals 6700 gpm, monthly flow equals 2700 gpm).

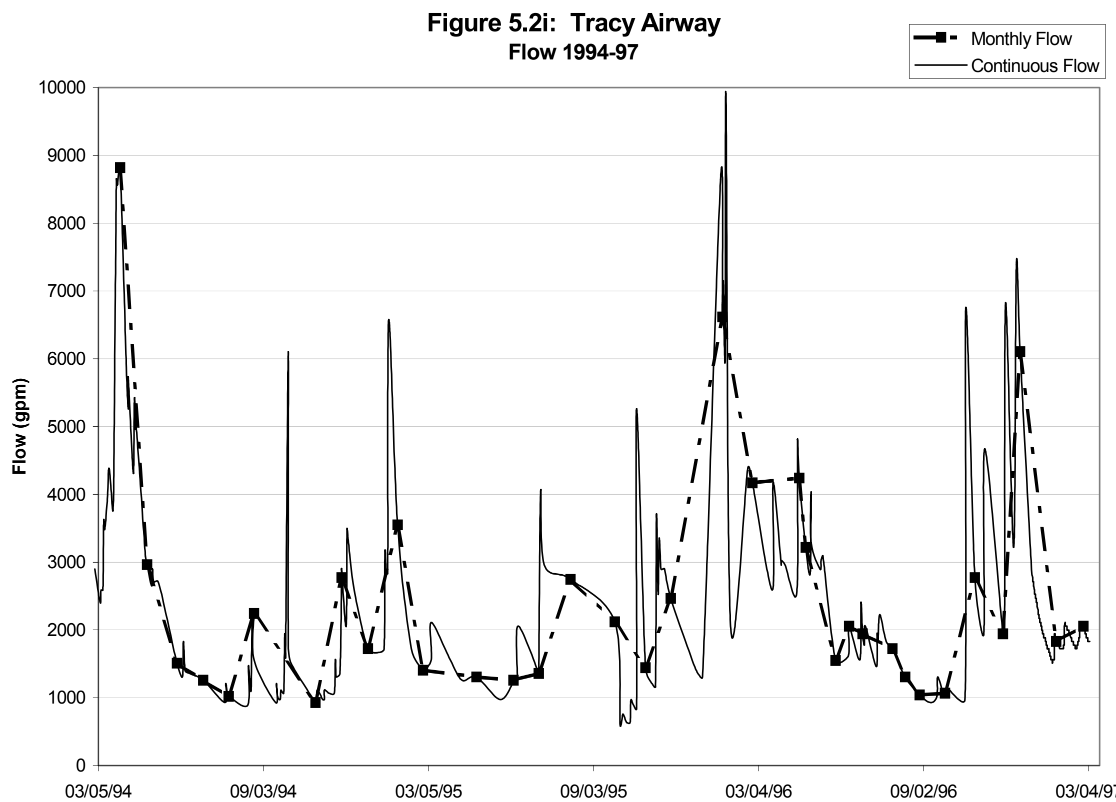


Figure 5.2i: Tracy Airway
Flow 1994-97
Monthly Flow
Continuous Flow
Flow (gpm)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
03/05/94
09/03/94
03/05/95
09/03/95
03/04/96
09/02/96
03/04/97

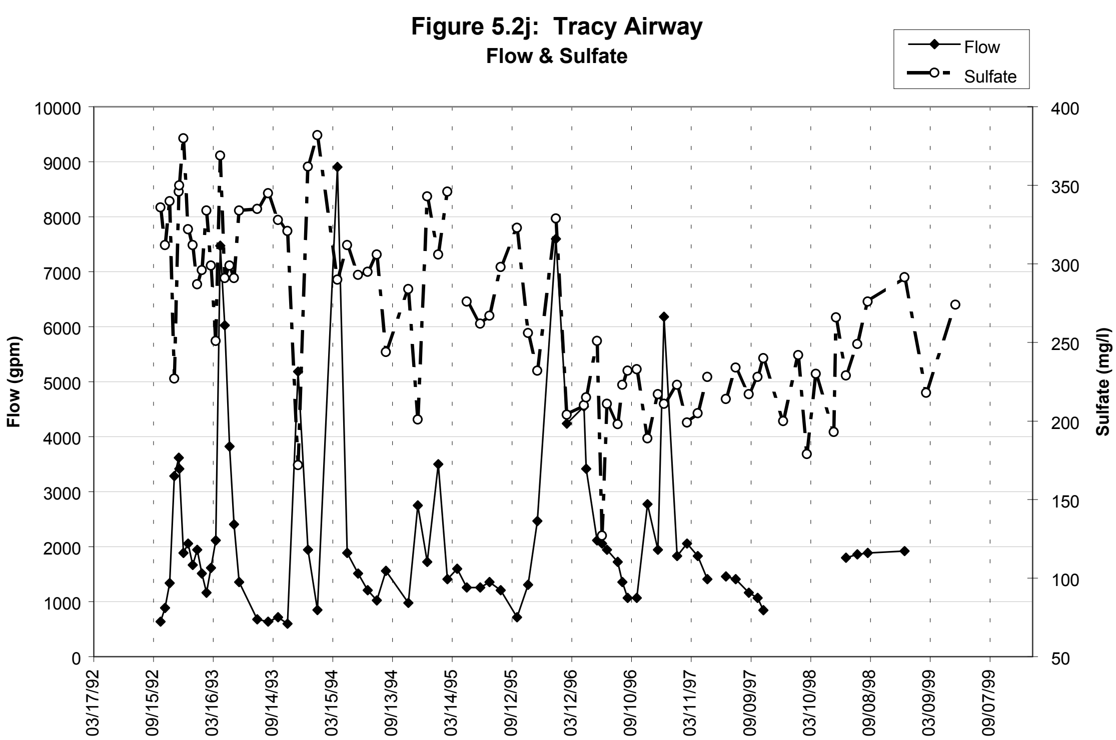


Figure 5.2j: Tracy Airway
Flow & Sulfate
Flow
Sulfate
Flow (gpm)
Sulfate (mg/l)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
400
350
300
250
200
150
100
50
03/17/92
09/15/92
03/16/93
09/14/93
03/15/94
09/13/94
03/14/95
09/12/95
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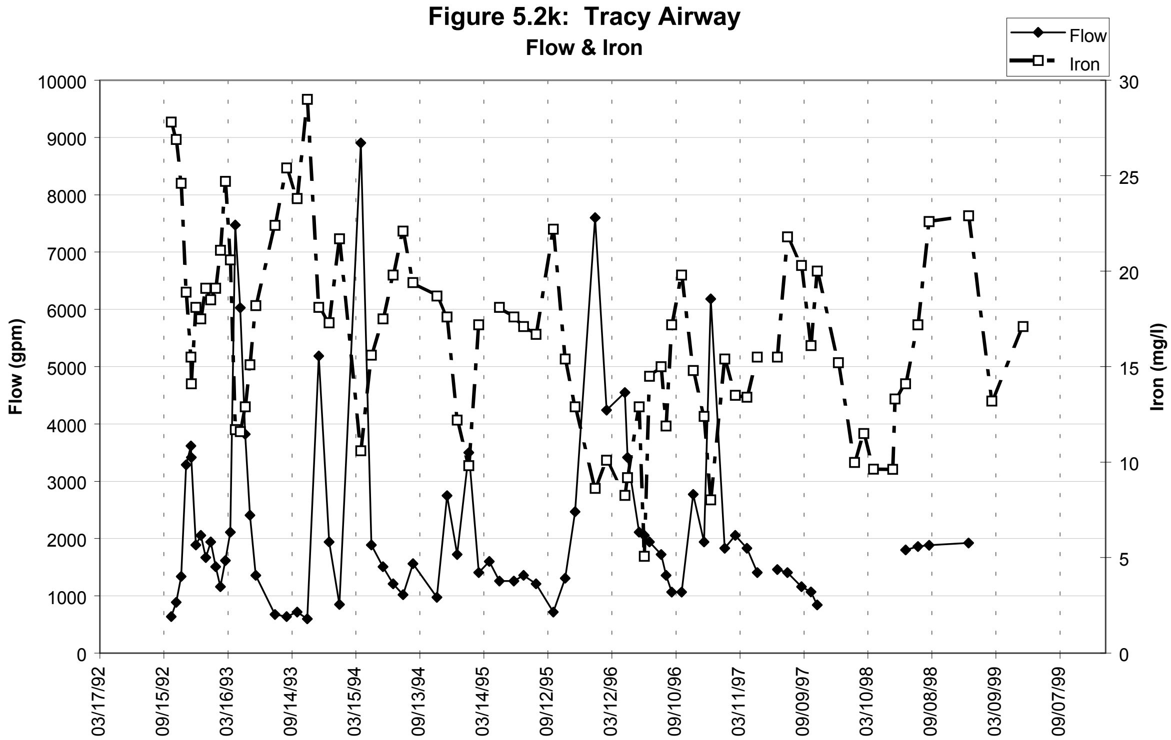
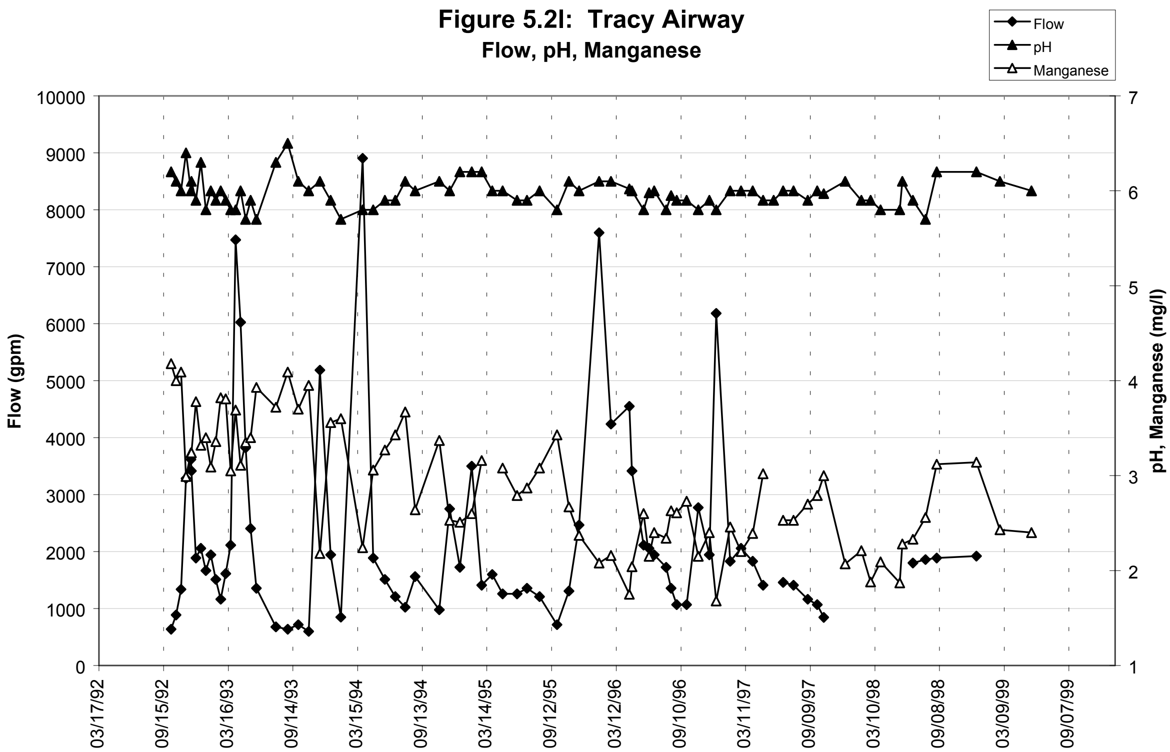
09/10/96
03/11/97
09/09/97
03/10/98
09/08/98
03/09/99
09/07/99



In comparing continuous flow data (Figure 5.2i) to monthly flow data, most of the Markson discharge results were also apparent in the Tracy discharge. While the monthly samples correspond well during the first two major high flow events in 1994 (April and September), several major storm events go undetected in the succeeding data (e.g., October and November 1994, November 1995, and November 1996). In addition, there are several major storm events where the monthly sample was collected after (February, July, and August 1995, and October 1996) or before (January 1996) the peak recorded by continuous monitoring. The differences between the monthly and continuous recorder data peaks are most significant in February 1995 (3700 and 6700 gpm), January 1996 (6500 and 9900 gpm), and October 1996 (2700 and 6700 gpm). One interesting characteristic of the Tracy flow data is that the continuous flow monitor results for 1995 "bottoms out" several hundred gallons per minute below the monthly data, but corresponds well with the low flow continuous recorder data for other water years.



A strong inverse relationship between flow and pollutant concentration in the Tracy discharge is shown in Figures 5.2j, 5.2k, and 5.2l, with the highest flows corresponding to the lowest concentrations and the lowest flows corresponding to the highest concentrations for sulfate (Figure 5.2j), iron (Figure 5.2k), and manganese (Figure 5.2l). There appears to be a trend over time, where the range of median values for sulfate and manganese are diminished from 1992 through 1997.

Monthly flow and water quality relationships of the Markson and Tracy discharges, throughout the eight year period shown in Figures 5.2b through 5.2l, indicate a general inverse relationship between flow and concentration, but also show that the distribution, magnitude, and duration of high flow events is not uniform from water year to water year. In fact, sometimes the highest flow events appear during what is traditionally the low flow period of the water year (e.g., October 1996 and September 1999). These data suggest that a sampling interval length of not greater than one month, and a sampling duration of at least a water year (12 monthly samples) are necessary to document baseline flow and water quality variations, particularly if high flow events are important in establishing the baseline pollution load. The monthly and continuous flow data for the Markson and Tracy discharges (Figures 5.2g and 5.2i) show that representative sampling of storm events can be tricky, as isolated sampling events may not always capture the range and pattern of natural seasonal variations. This problem is illustrated in Figures 5.2g and 5.2i, where monthly flow measurements indicate high flows that are much lower than those measured by the continuous flow monitors, or where significant high-flow periods detected by continuous monitoring were undetected by the monthly measurements.

5.2.3 Swatara Creek Monitoring Station

USGS has been sampling water quality and flow characteristics of Swatara Creek in Schuylkill and Lebanon Counties, Pennsylvania since before 1960. The results of this data collection are found in numerous publications including McCarren et al. (1961) and Fishel and Richardson (1986). The USGS Ravine Station shown in Figure 5.2a has been a key station because it is located on the main stem of Swatara Creek immediately below the confluence of several tributaries draining the coal operations in the Swatara Creek headwaters. Below the Ravine Station, the Swatara Creek watershed changes to a more agricultural land use without acid mine drainage contributions to water quality. Figures 5.2m, 5.2n, and 5.2o contain a series of plots of the storm-flow hydrograph and continuous measurements of specific conductance and pH for a five day period in December 1996 (Cravotta, personal communication). These figures also show water quality data for sulfate, suspended solids, and iron (total and dissolved) that were collected by automatic samplers for flows resulting from this storm flow period. These figures indicate that water quality data peaks for suspended solids and iron precede the peak for flow. According to Cravotta (1999), the occurrence of these concentration peaks prior to peak flow are the result of scour and transport of stream bed deposits.

Figure 5.2m: Swatara Creek Flow and Sulfate Data

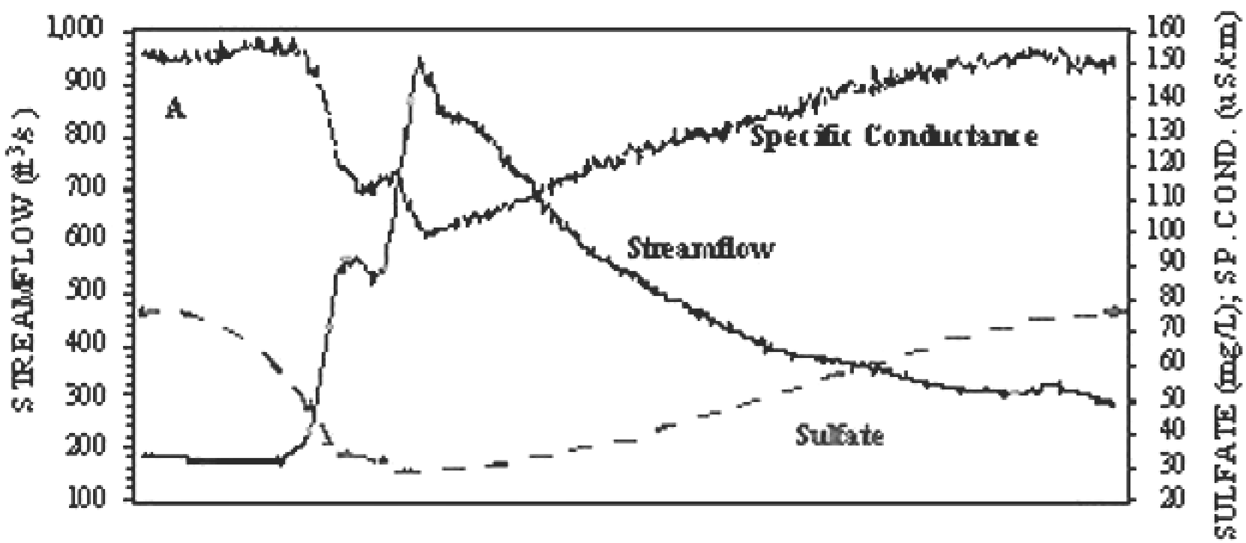


Figure 5.2n: Swatara Creek Flow and Suspended Solids Data

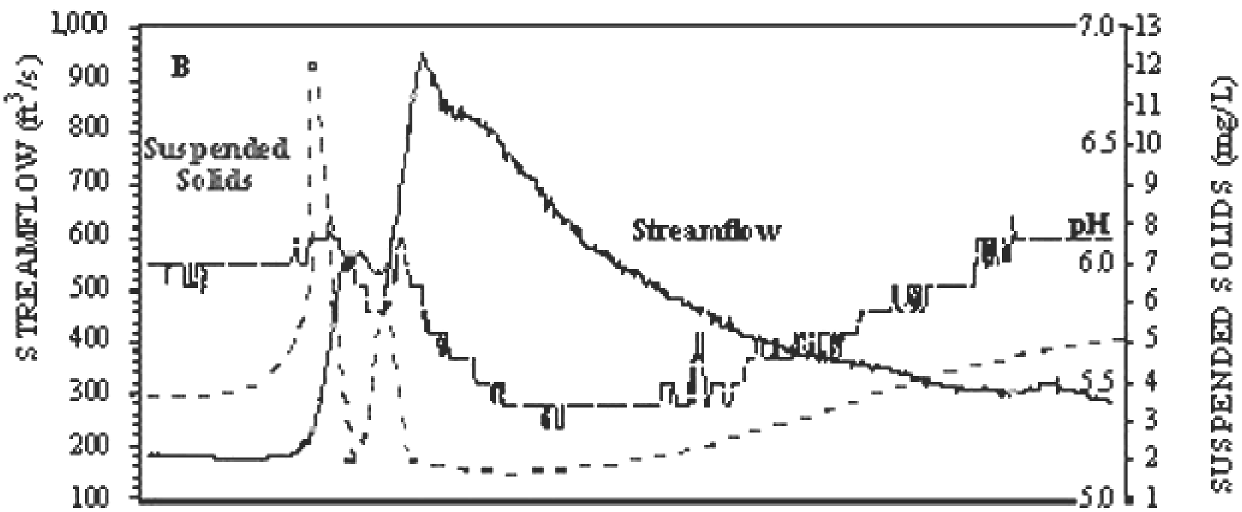
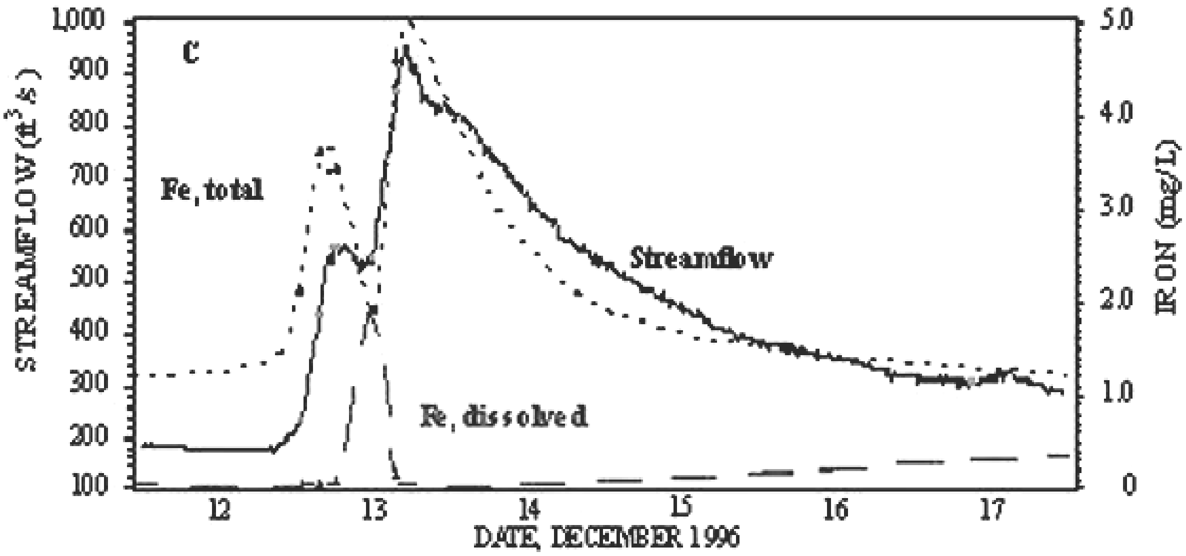


Figure 5.2o: Swatara Creek Flow and Iron Data



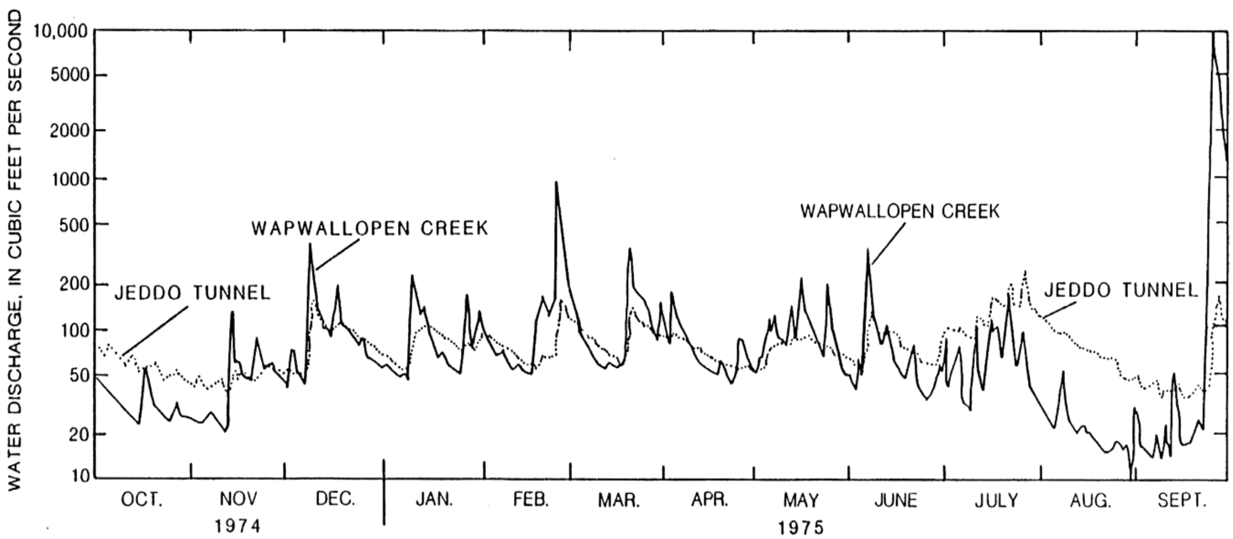
5.2.4 Jeddo Tunnel Discharge

The Jeddo Tunnel mine discharge near Hazleton Pennsylvania is the largest abandoned underground mine discharge in the Eastern Middle Field of the Anthracite Region, and is among the largest mine drainage discharges in Pennsylvania. The Jeddo Tunnel has a total drainage area of 32.24 square miles, and its underground drainage system collects and discharges more than half of the precipitation received in the drainage area (Balleron et al., 1999). The flow of this discharge was monitored with a continuous recorder from December 1973 through September 1979 by the USGS in cooperation with Pennsylvania Department of Environmental Resources.

The results of that monitoring for the water year from October 1, 1974 through September 30, 1975 are shown in Figure 5.2p (Growitz et al., 1985). During that year, the discharge ranged from 36 to 230 cfs (16,157 to 103,224 gpm). The Jeddo Tunnel discharge flows are compared to the stream-flow of Wapwallopen Creek (approximately 10 miles north of the Jeddo Tunnel).

The Wapwallopen Creek drains an area of 43.8 square miles and has a measured mean discharge of 78 cfs (35,008 gpm) (Growitz et al., 1985). Growitz et al. found that the response of the Jeddo Tunnel discharge to precipitation events is considerably less than that of the Wapwallopen Creek, and that during large storm events, the Jeddo Tunnel data peaked later than the stream discharge.

Figure 5.2p: Jeddo Tunnel Discharge and Wapwallopen Creek Flow Data



The continuous flow recording station at the mouth of the Jeddo Tunnel was reconstructed and operated by USGS from October 1995 through September 1998 in cooperation with PA DEP, the Susquehanna River Basin Commission, US EPA, and other project cooperators. Figure 5.2q (from Balleron et al., 1999) shows variations in the flow of this discharge during this period. The average annual discharge flow was 79.4 cfs (35,635 gpm) and the range of recorded flow measurements was between 20 cfs (8,976 gpm) in October 1995 and 482 cfs (216,322 gpm) in November 1996, following 3.89 inches of rainfall (Balleron, 1999). Figure 5.2r shows a graph of precipitation data from Hazleton Pennsylvania for the period from October 1995 through September 1998. This graph was plotted from data contained in Balleron (1999).

Figure 5.2q: Jeddo Tunnel Flow Data

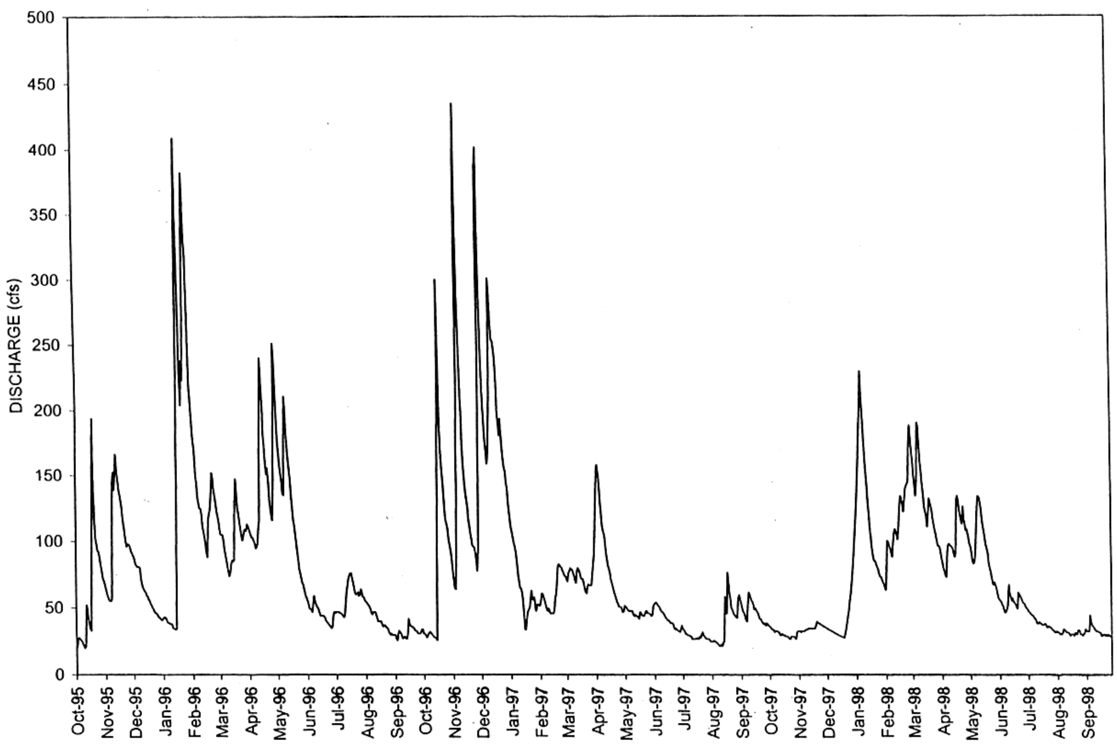
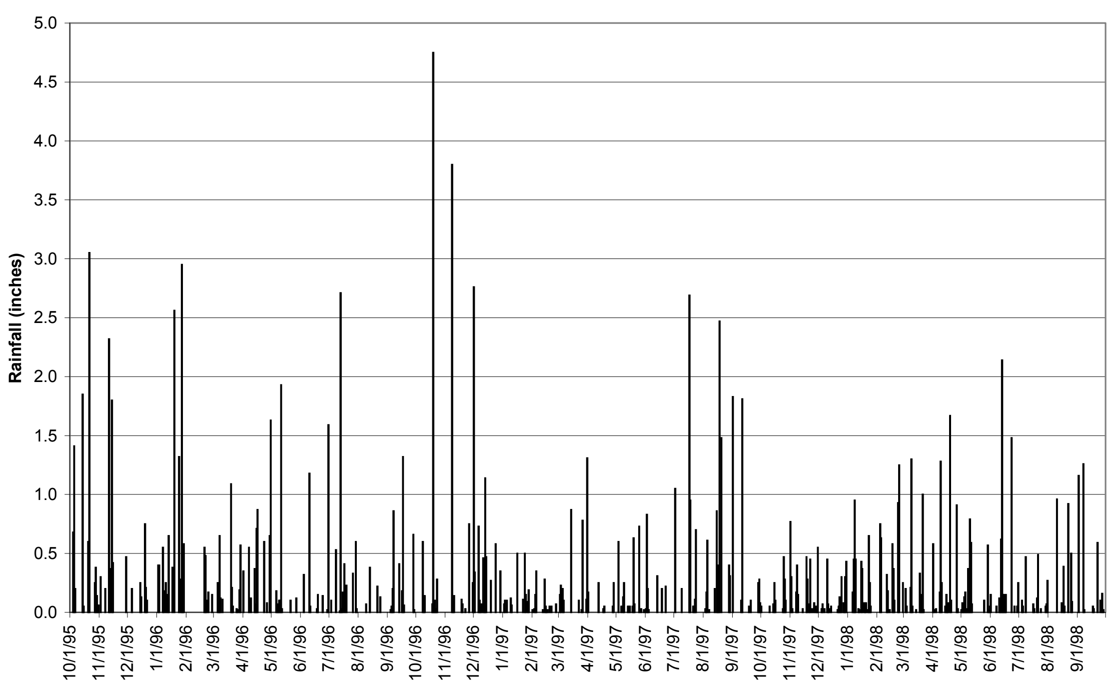


Figure 5.2(r): Precipitation Data From Hazleton, Pa



5.3 Case Studies

Baseline pollution loading in pre-existing discharges must be measured and monitored accurately to determine to what extent polluting conditions are affected by remining operations. The Fisher, McWreath, and Trees Mills remining sites in the Pennsylvania Bituminous Coal Region are presented as case studies in Section 5.3 to demonstrate significant changes in flow, water quality, and pollution load resulting from remining and reclamation activities. The case studies also demonstrate how a regular monitoring program can be used to evaluate and document both pre- and post-remining water quality from a pre-existing discharge. In each of these cases, monitoring was conducted at monthly intervals and proved to be adequate to document baseline conditions and to demonstrate post-remining changes in water quality. These case studies also illustrate the water quality and quantity changes that are typical of remining operations

5.3.1 Fisher Remining Site

The Fisher remining site is located in Lycoming County, Pennsylvania. Prior to remining, the surface of the site was extensively disturbed by abandoned surface mine pits and spoil piles. A large abandoned underground mine known as the Fisher deep mine occupied much of the sub-surface. The principal discharge (monitoring point M-1) was the main concern during the remining permit process. Baseline pollution load data collection took place between 1982 and 1985. The original remining permit was issued on November 5, 1985, and remining operations commenced by February 1986. Final coal removal occurred in June 1995 and backfilling was completed within the permit area by February 1996.

The best management practices employed on the Fisher remining site include: (1) daylighting the abandoned Fisher deep mine, (2) regrading abandoned spoils and backfilling abandoned pits, (3) alkaline addition, and (4) biosolids used for revegetation enhancement. Alkaline addition was accomplished with 140,000 tons of limestone fines on the two most recently permitted areas, resulting in an alkaline addition rate of approximately 400 tons per acre over an area of approximately 350 acres. Biosolids were applied to approximately 500 acres.

The relationships between the sulfate, iron, and manganese concentrations, and flow in the M-1 discharge for the period between 1982 and 1999, are shown in Figure 5.3a. There are several trends in the relationships resulting from remining activities. While iron concentrations decreased over time, sulfate and manganese concentrations increased. Discharge flow increased following backfilling (1996), probably because this point became the down gradient drain for greater than 500 acres of unconsolidated mine spoil aquifer materials. The most significant change in pollutant concentration was in net acidity (Figure 5.3b). Prior to activation of the remining permit, the acidity concentration was typically in the range of 100 to 200 mg/L. The effect of remining was to turn a distinctly acidic discharge into one that is now distinctly alkaline (i.e., post-mining net acidity concentrations of 0 through –75 mg/L).

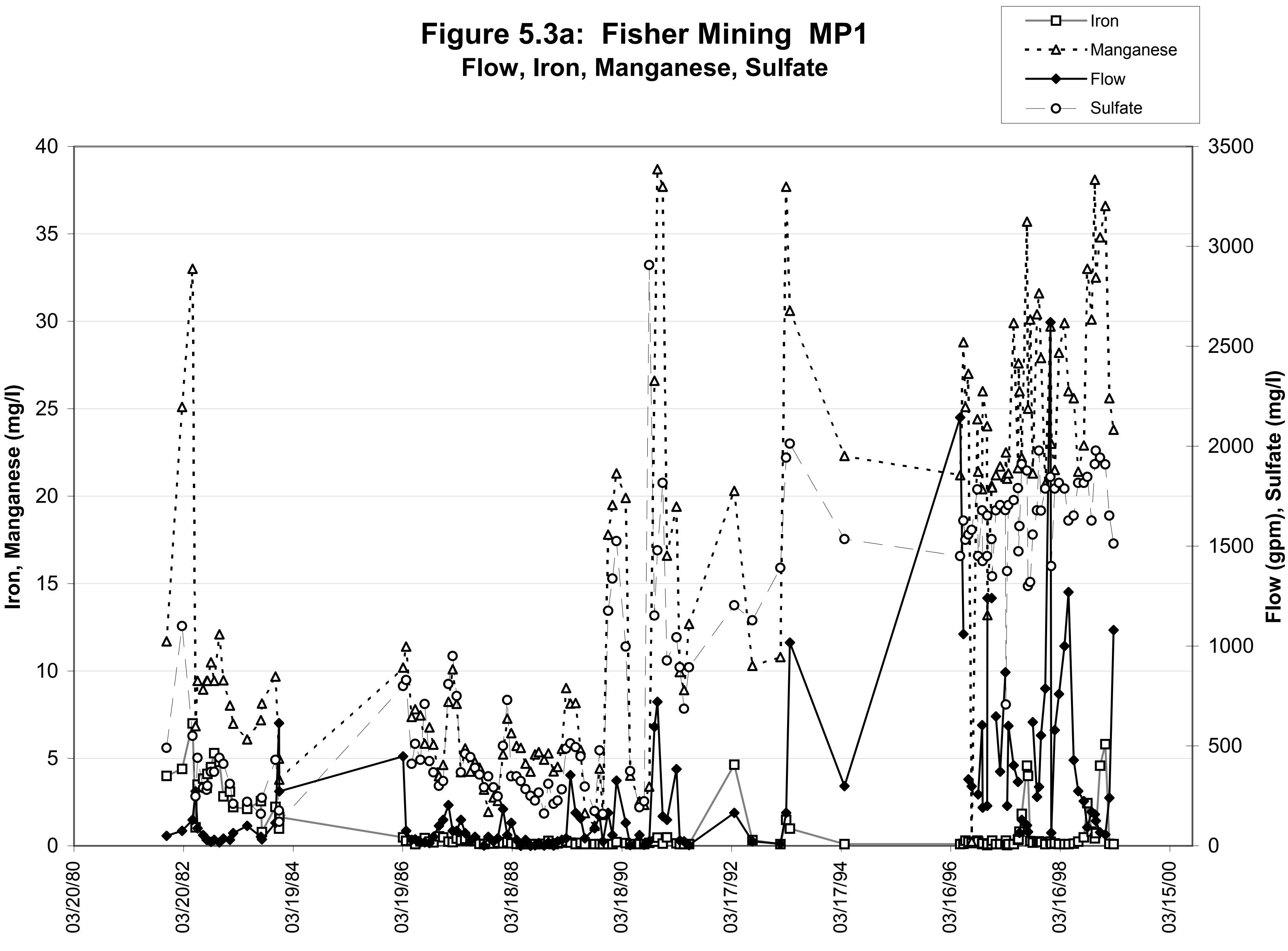


Figure 5.3a: Fisher Mining MP1
Flow, Iron, Manganese, Sulfate
Iron
Manganese
Flow
Sulfate
Iron, Manganese (mg/l)
Flow (gpm), Sulfate (mg/l)
40
35
30
25
20
15
10
5
0
3500
3000
2500
2000
1500
1000
500
0
03/20/80
03/20/82
03/19/84
03/19/86
03/18/88
03/18/90
03/17/92
03/17/94
03/16/96
03/16/98
03/15/00

Figure 5.3b: Fisher Mining MP1
Net Acidity

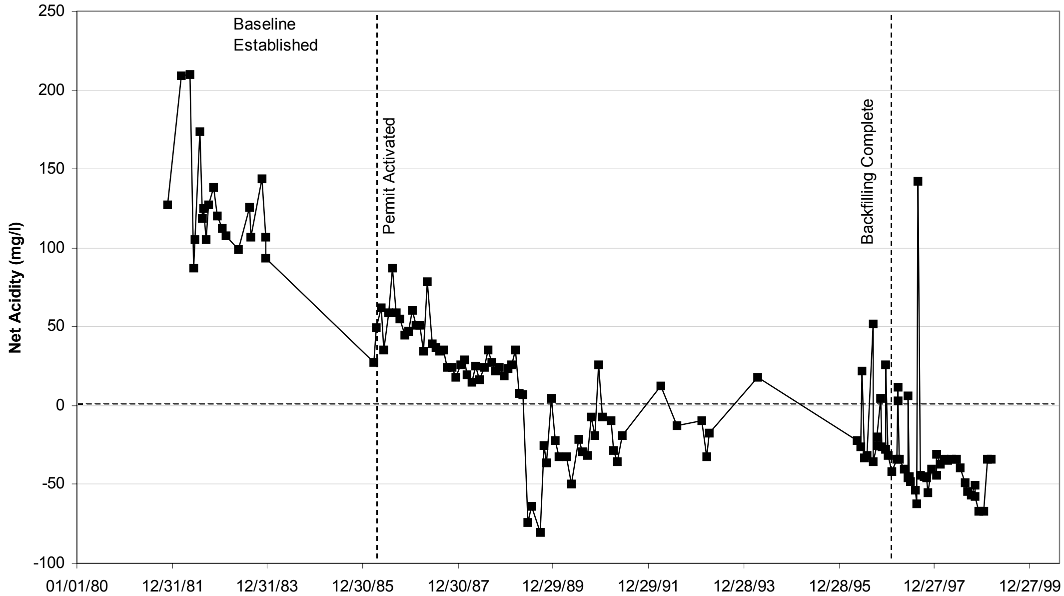
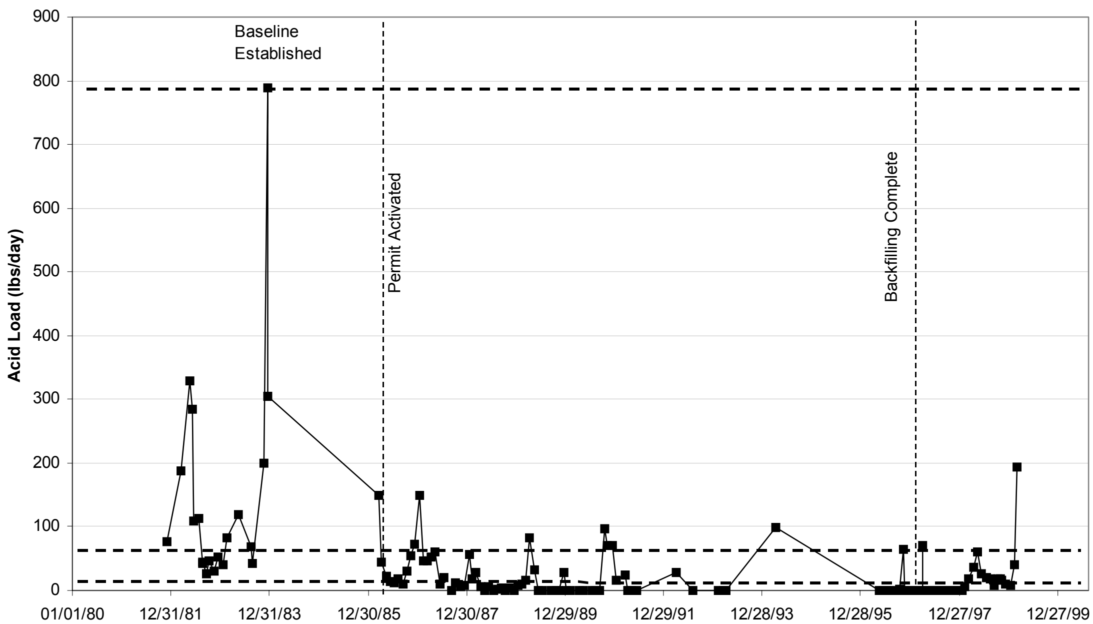


Figure 5.3c: Fisher Mining MP1
Acid Load



The Fisher permit (and most remining permits in Pennsylvania) was written in a format that evaluates remining performance on a pollution load basis rather than a concentration basis. As part of the baseline pollution load computation, quality control limits are based upon the approximate 95 percent tolerance limits around the frequency distribution, and the median is used as the measure of central tendency of the frequency distribution (see Section 1.0, Table 1.2a). Acidity loading prior to permit activation (baseline establishment), during open pit mining, and following backfilling and reclamation for the M-1 discharge are shown in Figure 5.3c. The upper and lower of the three horizontal dashed lines correspond to the upper and lower 95 percent tolerance limits for the pre-mining baseline pollution load. The middle dashed line is the baseline median acidity load (67.9 pounds per day). The median acidity load for the three year period following backfilling (1996 through 1999) is 0 pounds per day, showing improvement in water quality. Figure 5.3d shows corresponding improvement in the iron load (pre-mining baseline median iron load was 1.36 pounds per day; median of the three years following backfilling is 1.04 pounds per day). The differences in iron load and in net alkalinity concentration during these time periods are presented in Figures 5.3e and 5.3f respectively.

Figure 5.3e: Iron Load Boxplot

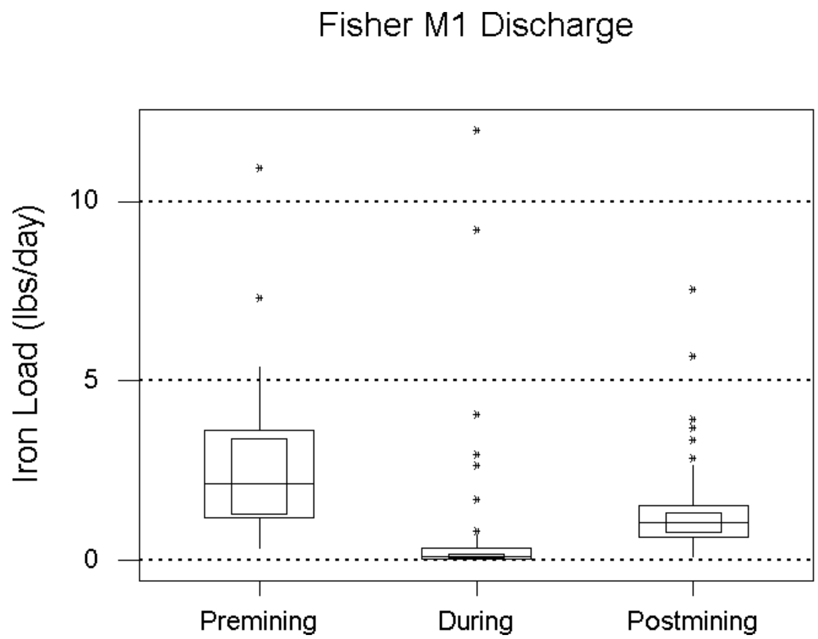
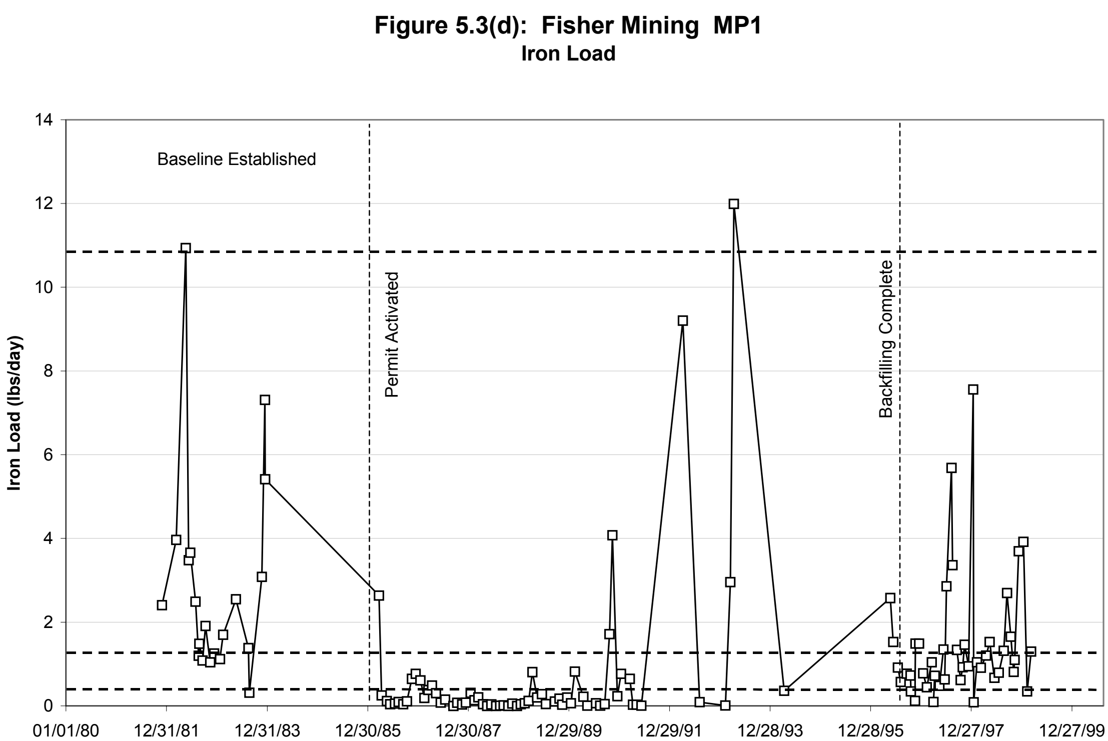


Figure 5.3f: Net Alkalinity Boxplot



5.3.2 McWreath Remining Site

The McWreath remining site is located in Robinson Township, Washington County, Pennsylvania. The initial surface mining permit for this remining operation was issued on July 21, 1987 for 112.1 acres. The principal best management practice in the remining plan was daylighting of an abandoned underground mine. In this area of Washington County, the overburden of the Pittsburgh Coal includes extensive calcareous strata which produce alkaline mine drainage when disturbed. A similar daylighting example for pH changes at the Solar mine of the Pittsburgh Coal seam, in Allegheny County, Pennsylvania is included in Brady, 1998. The McWreath site had three pre-existing pollution discharges emanating from abandoned underground mine workings prior to remining (monitoring points D-1, D-3, and D-4). The remining operation mined through these discharge locations, and the effects on the flow and water quality are shown in Figures 5.3g through 5.3j.

The flow and concentrations of net acidity, sulfate, iron, manganese, and aluminum in the D-1 discharge are shown in Figure 5.3g. This was the largest of the three deep mine discharges at the McWreath site. This discharge had four sampling events during baseline data collection and following permit issuance when the flow was between 35 and 40 gallons per minute. In April of 1990, the discharge dried up, only briefly reappearing as a 1.2 gallon per minute flow in December 1990, and as a 10 gallon per minute flow in December 1992. According to monthly monitoring data, the discharge has otherwise gone dry as a result of remining from 1990 to present. Flow and concentrations of iron, manganese, acidity, sulfate, and aluminum in the D3 and D4 discharges are shown in Figures 5.3h through 5.3j.

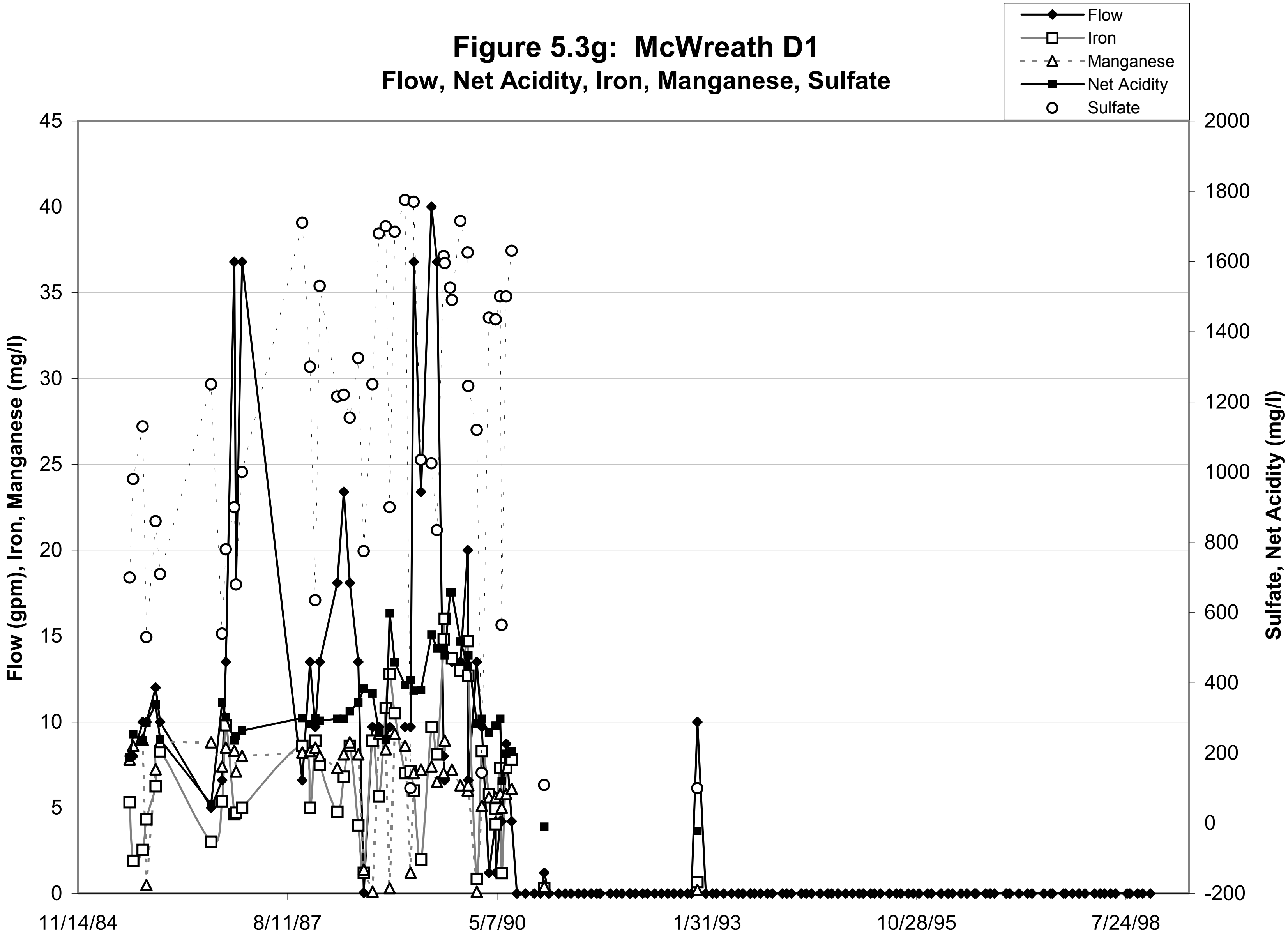


Figure 5.3g: McWreath D1
Flow, Net Acidity, Iron, Manganese, Sulfate
Flow
Iron
Manganese
Net Acidity
Sulfate
Flow (gpm), Iron, Manganese (mg/l)
Sulfate, Net Acidity (mg/l)
45
40
35
30
25
20
15
10
5
0
2000
1800
1600
1400
1200
1000
800
600
400
200
0
-200
11/14/84
8/11/87
5/7/90
1/31/93
10/28/95
7/24/98

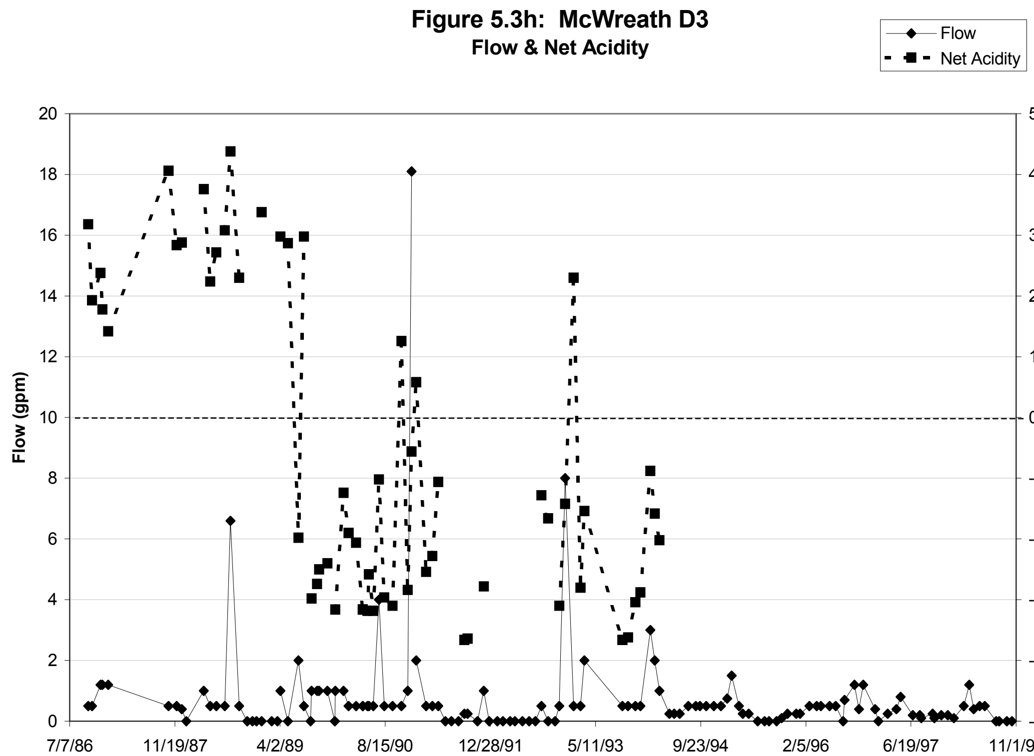


Figure 5.3h: McWreath D3
Flow & Net Acidity
Flow
Net Acidity
Flow (gpm)
Net Acidity (mg/l)
20
18
16
14
12
10
8
6
4
2
0
500
400
300
200
100
0
-100
-200
-300
-400
-500
7/7/86
11/19/87
4/2/89
8/15/90
12/28/91
5/11/93
9/23/94
2/5/96
6/19/97
11/1/98

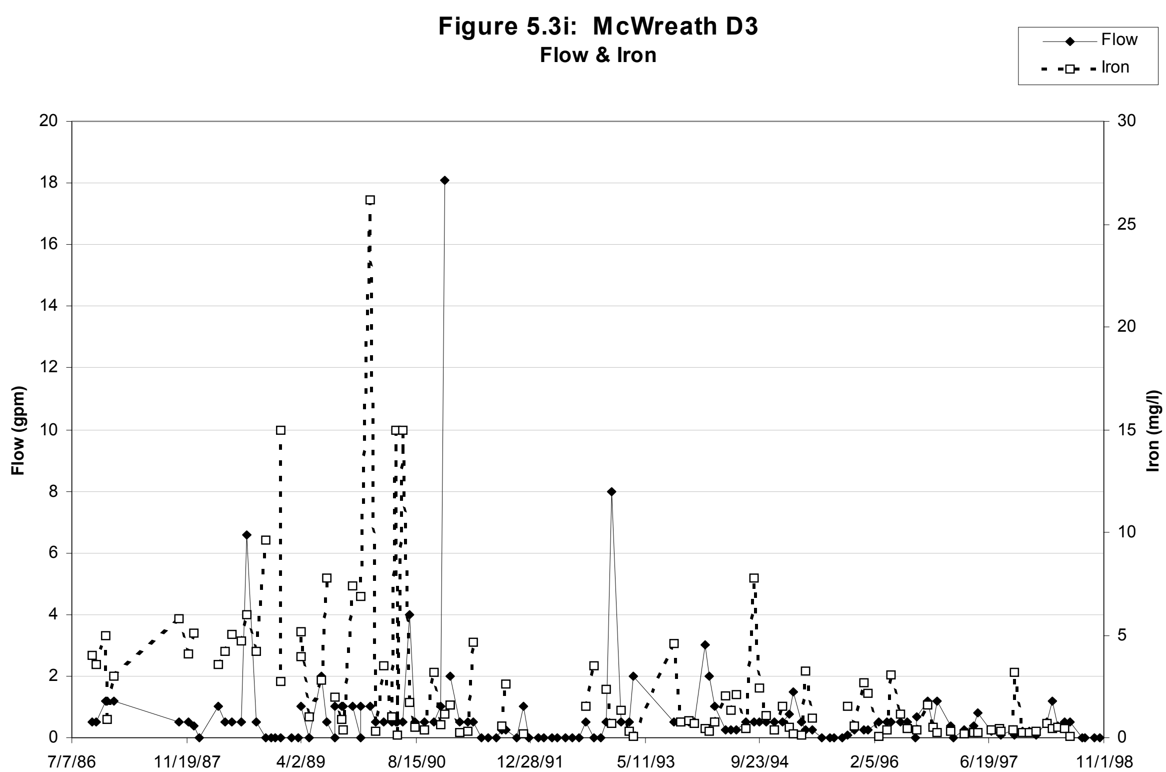
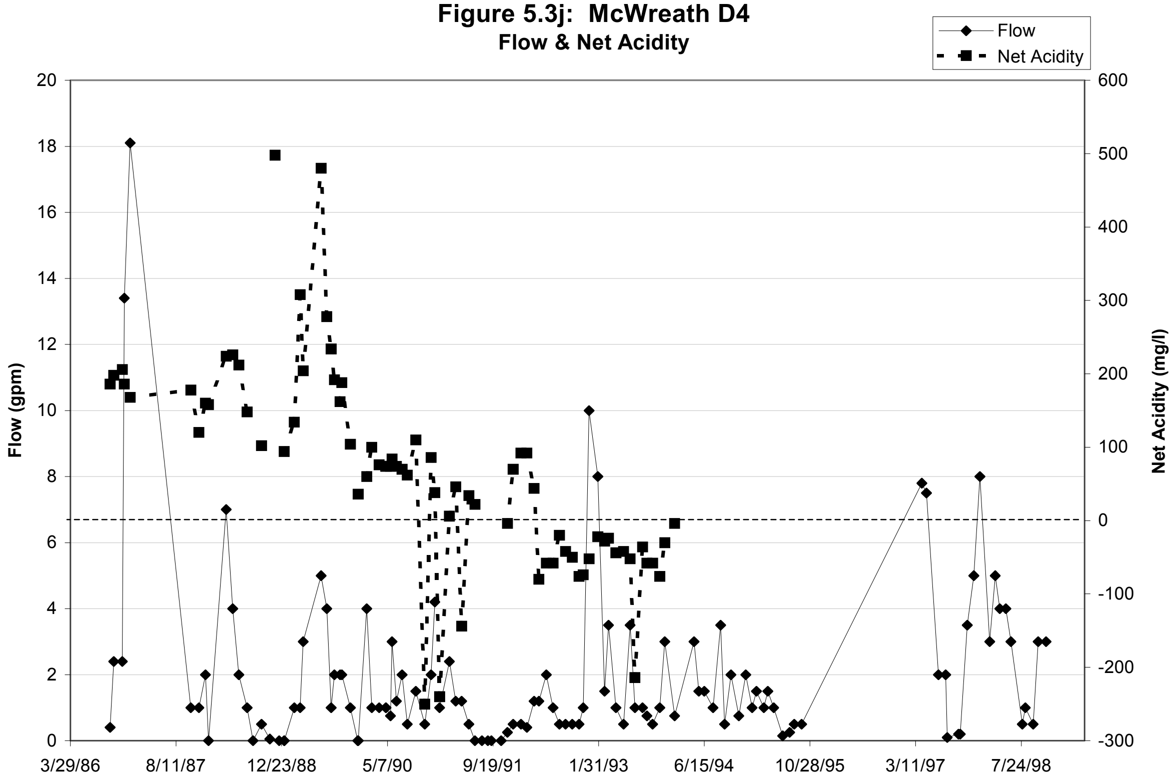


Figure 5.3i: McWreath D3
Flow & Iron
Flow
Iron
Flow (gpm)
Iron (mg/l)
20
18
16
14
12
10
8
6
4
2
0
30
25
20
15
10
5
0
7/7/86
11/19/87
4/2/89
8/15/90
12/28/91
5/11/93
9/23/94
2/5/96
6/19/97
11/1/98

Figure 5.3h shows a dramatic change in net acidity concentration which was in the range of 200 to 400 mg/L in 1986 and 1987, but since 1989, has dropped to predominantly less than 0 and as low as -350 mg/L. Figure 5.3j shows a substantial reduction in iron concentration since 1990. Most of the flow measurements from 1996 through 1999 in Figures 5.3h and 5.3i are less than 2 gallons per minute.

The D-4 discharge had a pre-mining flow intermediate between discharge D-3 and D-1, and recent flow measurements for this discharge are several times higher than the D-3 discharge. Figure 5.3j depicts a large change in net acidity concentration as a result of remining on the McWreath site, where the net acidity prior to 1990 was always greater than 100 mg/L and as high as 500 mg/L, and the net acidity since 1990 is always less than 100 mg/L and as low as -250 mg/L. Therefore, remining transformed two distinctly acidic discharges into distinctly alkaline discharges through daylighting the abandoned deep mine and exposing naturally alkaline overburden strata during remining and reclamation operations.

Figure 5.3j: McWreath D4
Flow & Net Acidity



5.3.3 Trees Mills Site

The Trees Mills remining site is situated in Salem Township, Westmoreland County, Pennsylvania (Figure 5.3k). The remining permit boundary is shown in this figure as a bold line. The surface mining permit for the 325 acre site was issued on May 25, 1990. Surface water drainage from the permit area flows to Beaver Run to the West and Porter Run to the East. Beaver Run is classified as a High Quality – Cold Water Fishery, and the Beaver Run Reservoir (a public water supply impoundment for 100,000 people) is located less than 2500 feet downstream from the Trees Mills remining site.

The primary best management practice in the pollution abatement plan for this site was the daylighting of an abandoned underground mine on the Pittsburgh Coal seam. There were also abandoned surface mine pits and highwalls that were regraded and reclaimed. As the result of extensive mine subsidence overlying the abandoned underground mine, prior to remining, much of the surface of the site resembled a waffle ground that promoted internal drainage to the abandoned deep mine workings rather than overland surface runoff. The geochemical characteristics of the overburden strata were more conducive to acidity production than alkalinity production. Figure 5.3l (Brady et al., 1998) features drill hole data for this site. Geochemical information listed on the left hand side of the bore holes in this figure represent percent sulfur; information listed on the right hand side represent neutralization potential in $CaCO_3$ equivalents. Except for high sulfur shale strata immediately overlying the coal, the overburden strata are characterized by a thick sandstone unit with several zones of relatively high sulfur. Only two sandstone samples in OB-2 have appreciable neutralization potential. The overburden quality of the Pittsburgh Coal at the Trees Mills site is much different (i.e., less calcareous strata, less alkalinity production potential) than at the McWreath site. Hence, the success of the remining pollution abatement plan for the Trees Mills site is more dependent on the hydrogeologic characteristics than on the geochemical characteristics that were significant at the Fisher and McWreath remining sites.

Figure 5.3k: Trees Mills Site Map

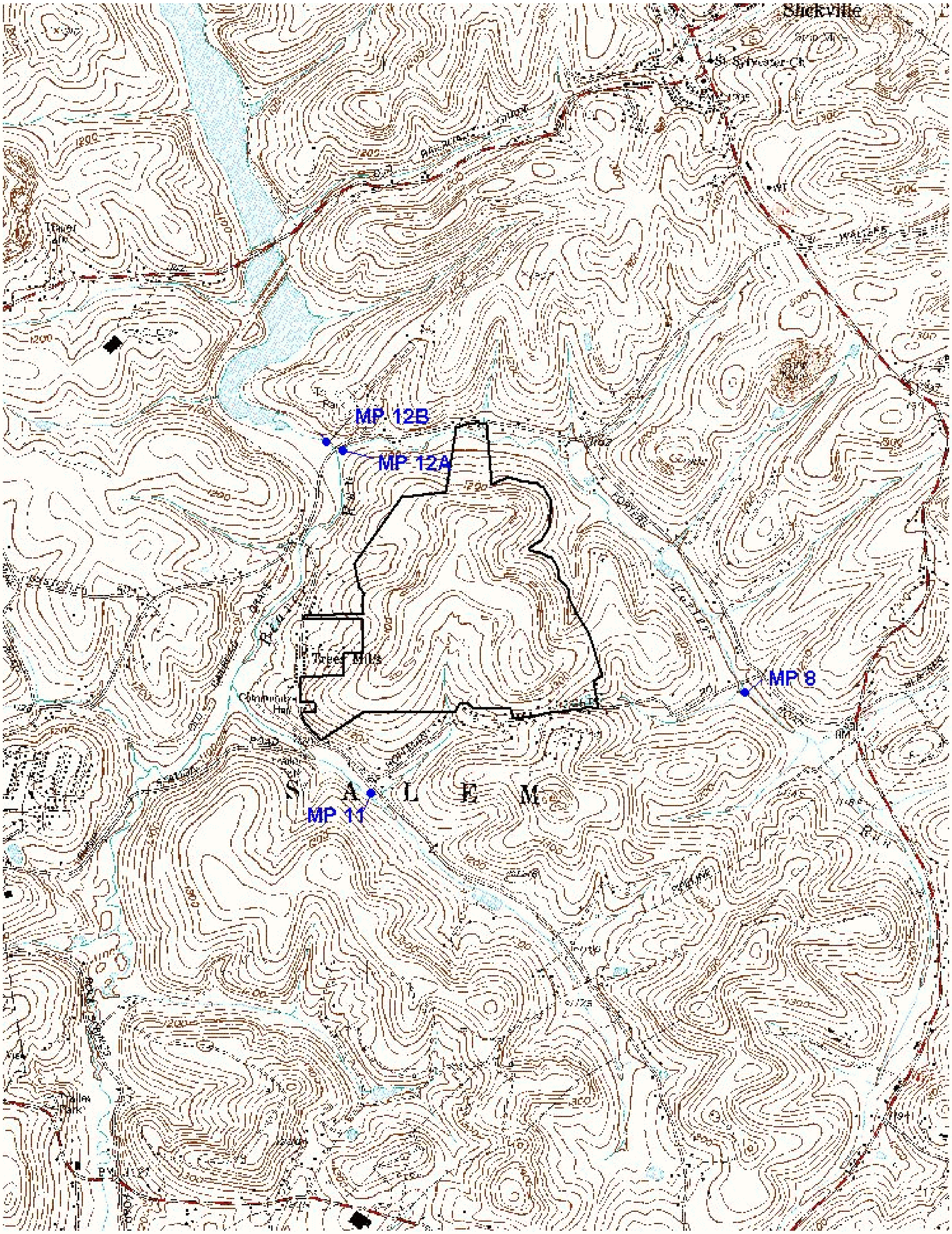
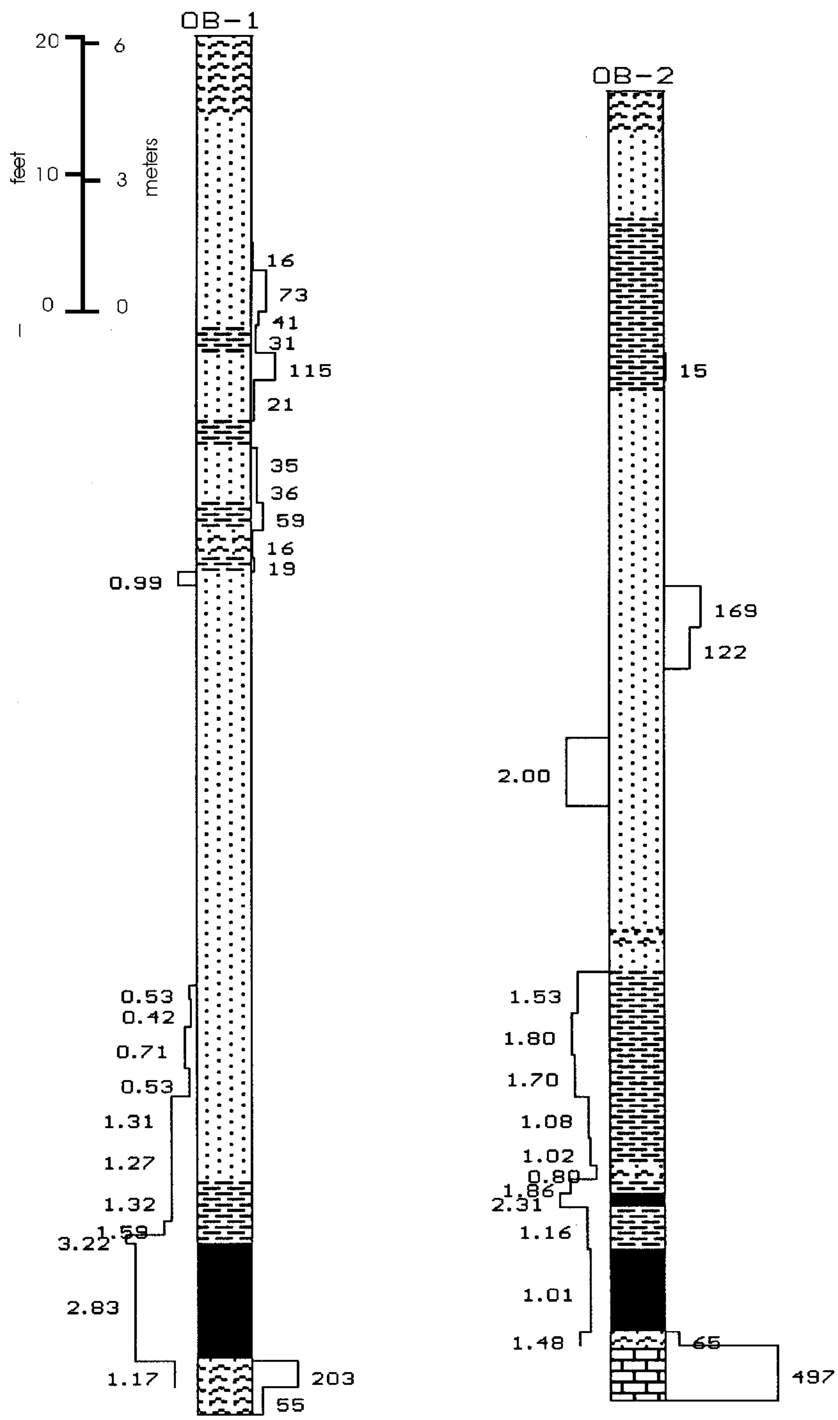


Figure 5.3l: Trees Mills Drill Hole Data



There were numerous acid mine drainage discharges and seeps emanating from the abandoned underground mine workings at the Trees Mills site prior to remining, and baseline pollution load statistical calculations were completed for ten of these monitoring points. The largest of these pre-existing discharges was MP-1 with pre-mining flows as high as 139 gallons per minute (Figure 5.3m and 5.3n). The effects of remining upon three other pre-existing discharges (MP-2, MP-3, and MP-6) will also be discussed. Because, remining operations commenced on the Trees Mills site on October 1991, water quality and flow data from 1987 through September 1991 can be considered pre-mining data. According to mine inspection reports, backfilling was completed by May 14, 1998, thus the intervening time from September 1991 through May 1998 includes the phases of active open pit mining and reclamation activities.

Figure 5.3m shows the variations in flow and concentrations of net acidity, sulfate, iron, manganese, and aluminum in the MP-1 deep mine discharge. The flow was highly variable prior to the initiation of mining in October 1991, ranging from less than one gpm to 139 gpm, with a median flow of 21.7 gpm and an average flow of 38.96 gpm. As the result of remining, the MP-1 discharge dried up by October 1992, reappearing in only one sampling event during the next seven years (0.26 gpm flow on March 3, 1998). The range in acidity concentrations for the period of July 1987 through October 1991 was 773 to 3,616 mg/L with a median of 1,336 mg/L and an average of 1,417 mg/L. The corresponding range in iron concentrations for the MP-1 discharge was 104 to 430 mg/L, with a median of 211 mg/L and an average of 224 mg/L.

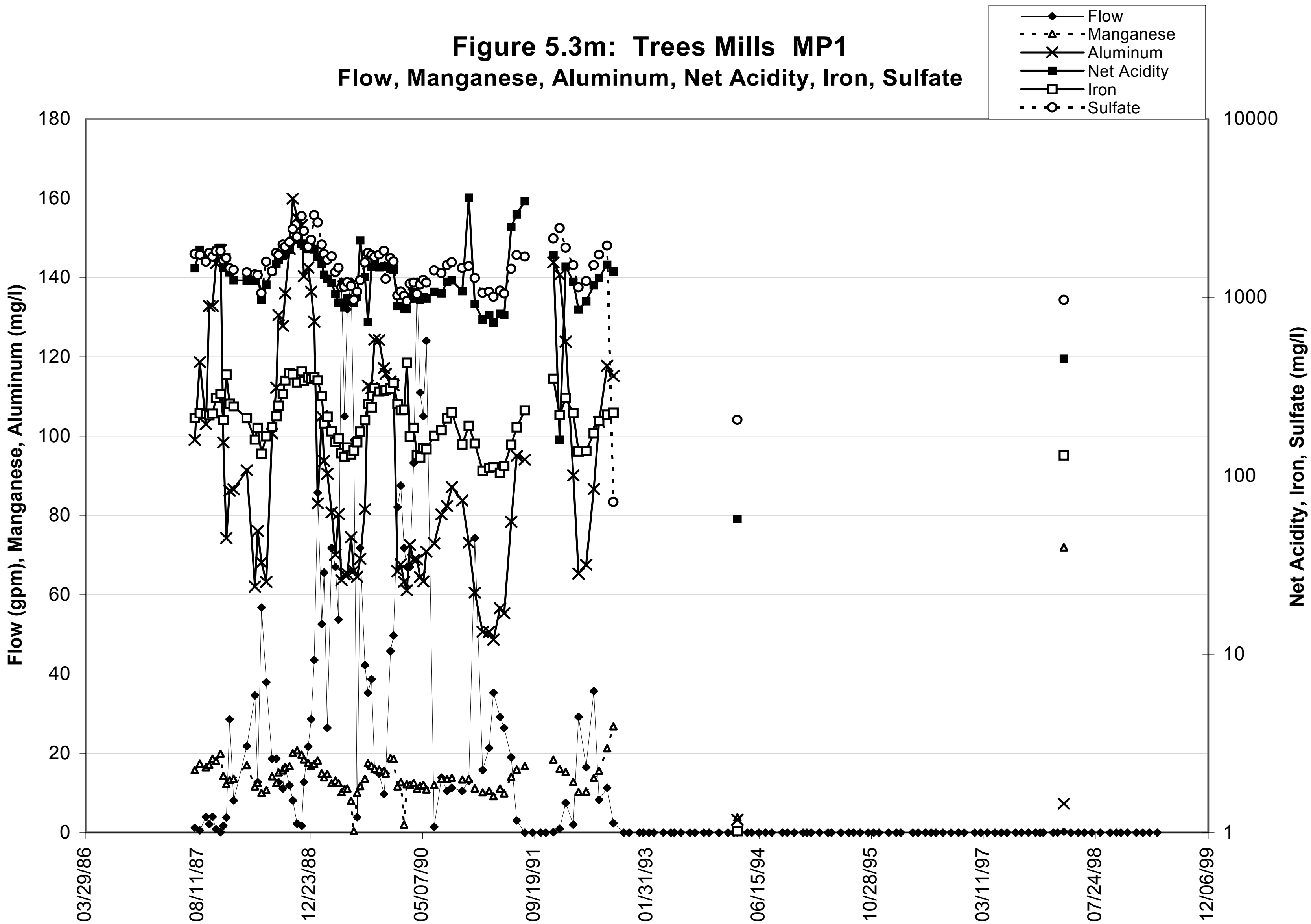


Figure 5.3m: Trees Mills MP1
Flow, Manganese, Aluminum, Net Acidity, Iron, Sulfate
Flow
Manganese
Aluminum
Net Acidity
Iron
Sulfate
Flow (gpm), Manganese, Aluminum (mg/l)
Net Acidity, Iron, Sulfate (mg/l)
180
160
140
120
100
80
60
40
20
0
10000
1000
100
10
1
03/29/86
08/11/87
12/23/88
05/07/90
09/19/91
01/31/93
06/15/94
10/28/95
03/11/97
07/24/98
12/06/99

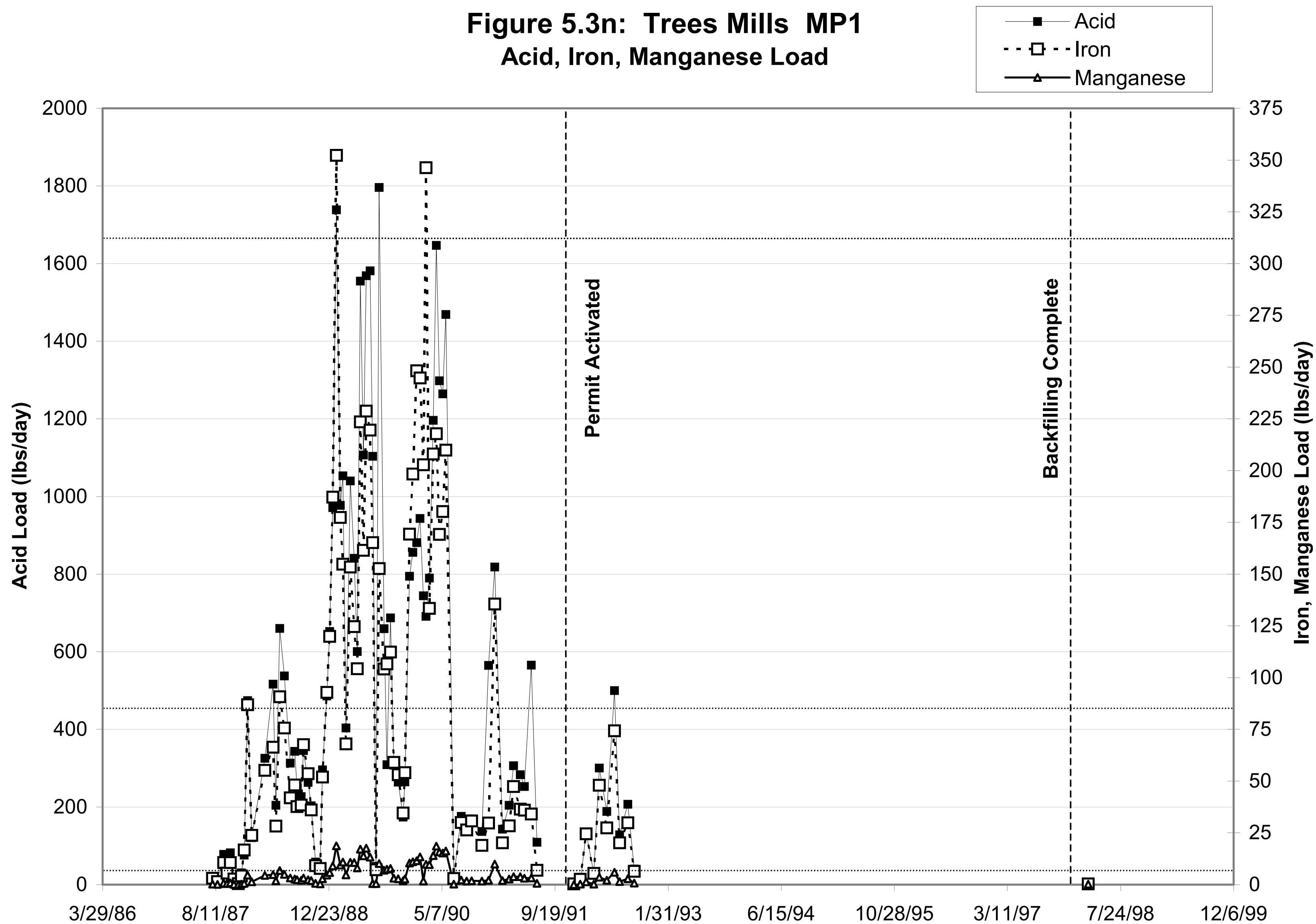


Figure 5.3n: Trees Mills MP1
Acid, Iron, Manganese Load
Acid
Iron
Manganese
Acid Load (lbs/day)
Iron, Manganese Load (lbs/day)
Permit Activated
Backfilling Complete
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
25
50
75
100
125
150
175
200
225
250
275
300
325
350
375
3/29/86
8/11/87
12/23/88
5/7/90
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3/11/97
7/24/98
12/6/99

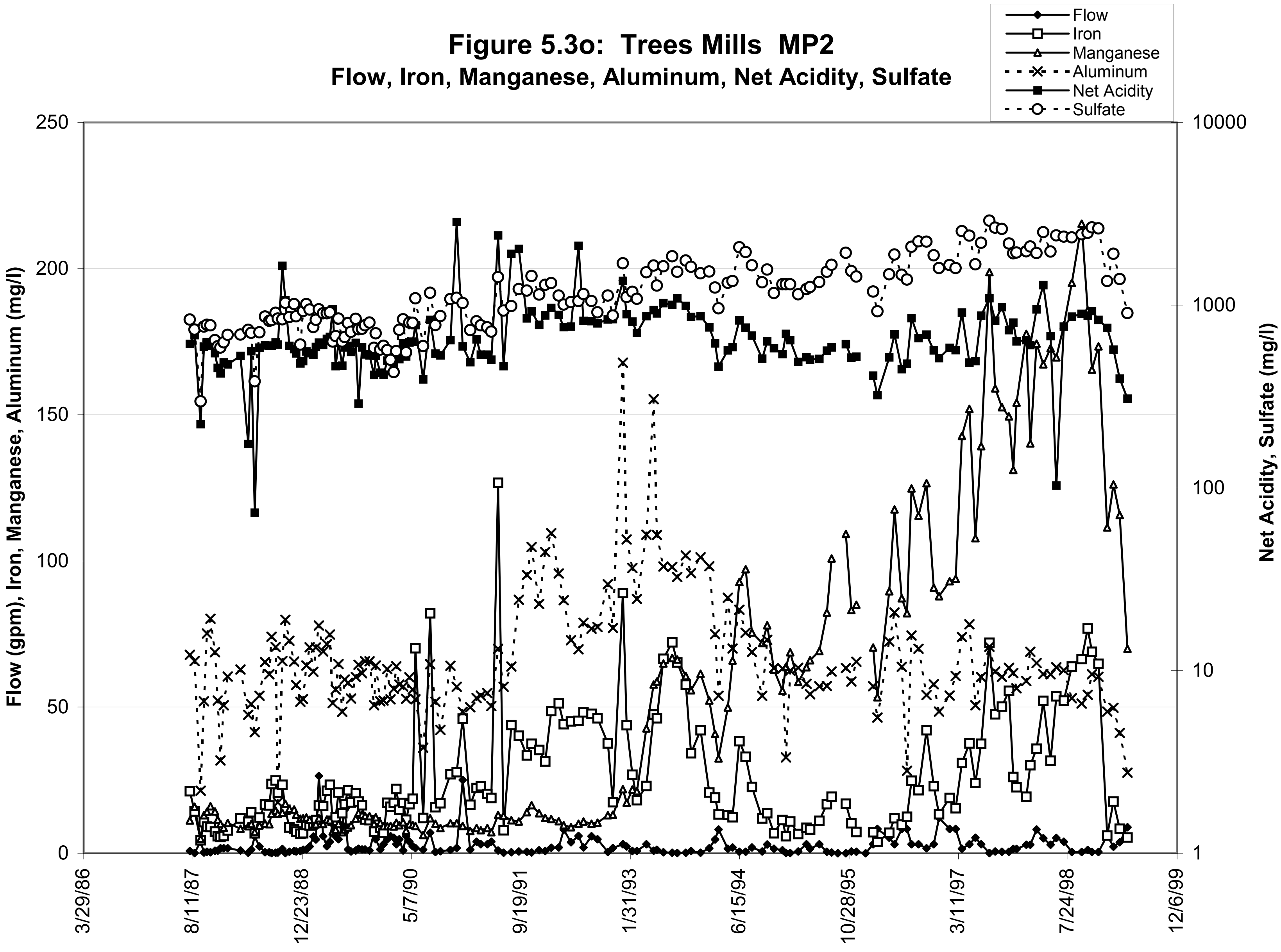
Figure 5.3o: Trees Mills MP2
Flow, Iron, Manganese, Aluminum, Net Acidity, Sulfate
Flow
Iron
Manganese
Aluminum
Net Acidity
Sulfate
Flow (gpm), Iron, Manganese, Aluminum (mg/l)
Net Acidity, Sulfate (mg/l)
250
200
150
100
50
0
10000
1000
100
10
1
3/29/86
8/11/87
12/23/88
5/7/90
9/19/91
1/31/93
6/15/94
10/28/95
3/11/97
7/24/98
12/6/99

Figure 5.3n shows the variations in the pollution load of acidity, iron, and manganese prior to and following permit activation. The three horizontal dashed lines represent the 95 percent tolerance levels around the frequency distribution of acid loads and the median value of 439 pounds per day acid load calculated in the baseline statistical analysis. The corresponding iron load was 71.8 pounds per day for the baseline sampling period. The median acid load during the period from October 1991 through October 1992 (while the discharge was still flowing) was 128.5 pounds per day and the corresponding iron load was 20.27 pounds per day. The remining operation at the Trees Mills site removed a significant acid load (439 pounds per day = 160,000 pounds per year) and iron load (71.8 pounds per day = 26,000 pounds per year) from the Beaver Run tributary and the Beaver Run public water supply reservoir.

Variations in flow and concentrations of acidity, sulfate, iron, manganese, and aluminum in the MP-2 discharge are shown in Figure 5.3o. Corresponding variations in acidity, iron, and manganese loads prior to permit activation, during mining, and following backfilling are shown in Figure 5.3n. This discharge had substantially lower flow than the MP-1 discharge. The range in flow prior to permit activation was 0.1 to 26.4 gpm (median of 1.3 gpm, average of 3.12 gpm). During active mining, the flow of the MP-2 discharge ranged from 0.02 to 12.1 gpm (median of 1.75, average of 2.66 gpm), while the flow following backfilling ranged from 0.39 to 8.9 gpm (median of 2.55, average of 2.97 gpm). Thus, while the range of flows decreased during mining and post-mining, the median flow increased by approximately one gpm. Net acidity, sulfate, and iron concentrations increased following permit activation (Figure 5.3m). Aluminum concentrations increased during mining but returned to pre-mining levels following backfilling. There also was a notable increase in manganese concentrations, from a median of 10.24 mg/L pre-mining to a median of 171.2 mg/L following backfilling.

The overall environmental impacts of these water quality changes are put in perspective by examining the pollution load data for MP-2 (Figure 5.3n), in comparison to the pollution load reduction achieved at the MP-1 location. The horizontal dashed lines represent the upper and lower 95 percent tolerance levels and the median baseline acid load. Baseline (pre-mining) acid load for MP-2 ranged from 0.31 to 197.6 lbs/day (median of 8.55). Post-backfilling acid load ranged from 3.89 to 54.95 lbs/day. Hence, while extreme values were reduced, median acid load increased by approximately 5 lbs/day. The range in pre-mining iron loads was 0.02 to 13.9 lbs/day (median of 0.26), while the post backfilling range was 0.3 to 3.36 lbs/day (median of 0.46). The range of pre-mining manganese loads was 0.02 to 3.79 lbs/day (median of 0.19), while the post-backfilling range was 0.78 to 10.6 lbs/day (median of 4.31). Based upon median values, there was an increase of 4.31 lbs/day of manganese from the MP-2 discharge, but an elimination of 3.22 lbs/day (average of 5.78 lbs/day) from MP-1. There was a corresponding increase of 0.2 lbs/day iron load from MP-2, with an elimination of 71.8 lbs/day from MP-1. Finally there was an increase of approximately 4.6 lbs/day acid load from MP-2, offset by the elimination of 439 lbs/day from MP-1.

The net effect on the Beaver Run receiving stream was a significant reduction in pollution loads. Variations in concentrations of net acidity, sulfate, iron, manganese, and aluminum from MP-3 (Figure 5.3q) are similar to that from MP-2, except for a significant reduction in iron concentration. Pre-mining iron concentrations in MP-3 ranged from 7.9 to 226.4 mg/L (median of 75), while the post-backfilling iron concentrations ranged from 6.55 to 84.72 mg/L (median value of 29.77). Pre-mining median manganese concentration was 11.18 mg/L, and the post-backfilling median was 194.55. Aluminum concentrations were 61.93 mg/L pre-mining and 63.38 mg/L post-backfilling. The flow of MP-3 ranged from 0.1 to 67 gpm pre-mining (median of 6.95), while post-backfilling flow ranged from 1.5 to 21.7 gpm (median of 3.95). Variations in acidity, iron, and manganese loads from MP-3 are shown in Figure 5.3r. Again, the horizontal dashed lines represent the upper and lower 95 percent tolerance levels and median value for pre-mining acid loads. The median baseline pollution load for acidity is 41.79 lbs/day compared to a post-backfilling median acid load of 34.79 lbs/day. The corresponding medians for iron loads

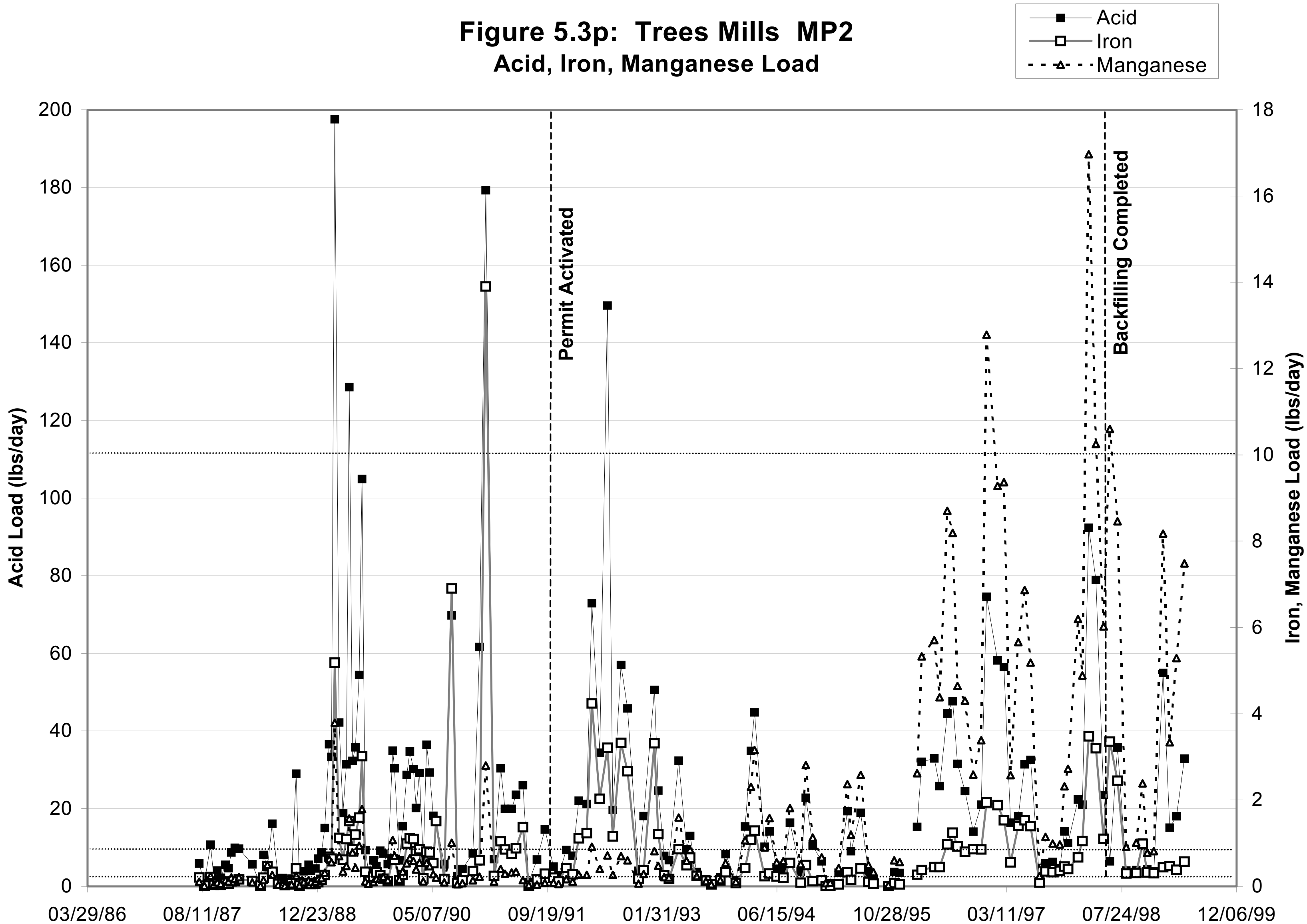
Figure 5.3p: Trees Mills MP2
Acid, Iron, Manganese Load
Acid
Iron
Manganese
Permit Activated
Backfilling Completed
Acid Load (lbs/day)
Iron, Manganese Load (lbs/day)
200
180
160
140
120
100
80
60
40
20
0
18
16
14
12
10
8
6
4
2
0
03/29/86
08/11/87
12/23/88
05/07/90
09/19/91
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03/11/97
07/24/98
12/06/99

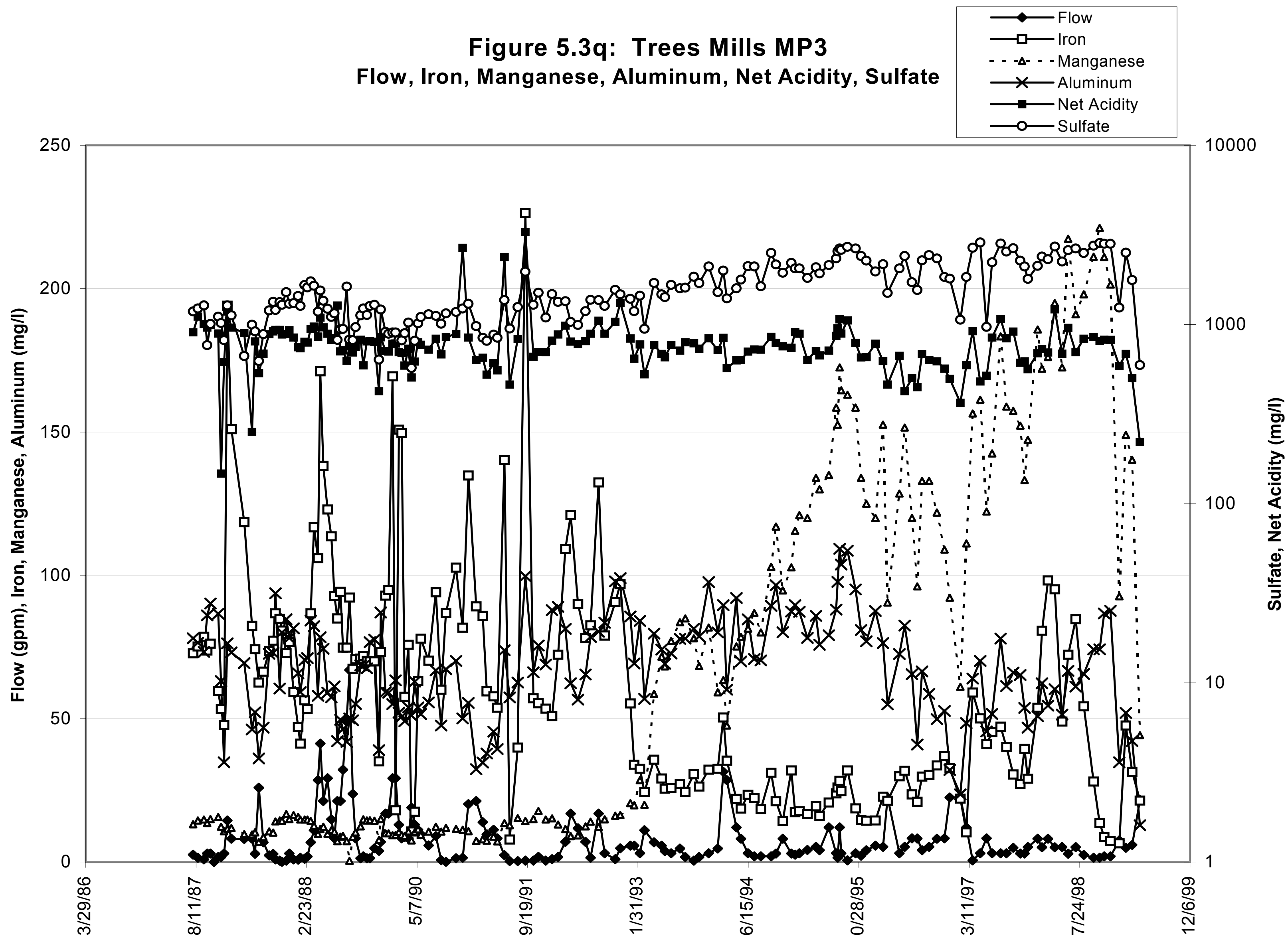


Figure 5.3q: Trees Mills MP3
Flow, Iron, Manganese, Aluminum, Net Acidity, Sulfate
Flow
Iron
Manganese
Aluminum
Net Acidity
Sulfate
Flow (gpm), Iron, Manganese, Aluminum (mg/l)
Sulfate, Net Acidity (mg/l)
250
200
150
100
50
0
10000
1000
100
10
1
3/29/86
8/11/87
12/23/88
5/7/90
9/19/91
1/31/93
6/15/94
10/28/95
3/11/97
7/24/98
12/6/99

are 4.03 lbs/day pre-mining and 1.95 following backfilling. The pre-mining median manganese load was 0.7 lbs/day, and increased to a median of 7.97 lbs/day post-backfilling. Extreme values of iron loads were substantially reduced following backfilling.

The MP-6 discharge is located below the outcrop of the Pittsburgh Coal seam, and varied in pre-mining flow from 0.8 to 62.4 gpm (median of 9.5). Following completion of backfilling, the range in flow is 0.39 to 21.7 gpm (median of 3.8). The pre-mining range of acidity concentration from the MP-6 discharge was 125 to 2,587 mg/L (median of 784.7), and the post-mining range was 522 to 968 mg/L (median of 804.5). The range of the iron concentrations pre-mining was 11.54 to 161.0 mg/L (median of 74.7), while the post-mining range was 31.64 to 94.73 mg/L (median of 55.62). The pre-mining range in manganese concentration was 6.62 to 19.24 mg/L (median of 11.3), while the post-mining manganese range was 14.63 to 30.14 mg/L (median of 26.06 mg/L). Again, the horizontal dashed lines in Figure 5.3u represent the median acid load and upper and lower 95 percent tolerance levels for baseline statistical calculations. The median acid load was 73.13 lbs/day pre-mining as compared to 38.08 lbs/day post-mining. The corresponding iron loads were a median of 7.5 pre-mining and 2.98 lbs/day post-mining. The pre-mining median load of manganese was 1.11 lbs/day, and was nearly equal to the post-mining median of 1.06 lbs/day.

Due to the cumulative effects of remining upon the MP-1, MP-2, MP-3, and MP-6 discharges, the Trees Mills remining operation has resulted in a significant reduction in the pollution load of acidity and metals (iron, manganese, and aluminum) to the receiving stream and the Beaver Run Reservoir. To determine whether these pollution reduction effects could be detected in the water chemistry of the receiving stream, the permittee’s self monitoring reports and PA DEP mining inspector’s monitoring data were evaluated from the same monitoring points located upstream and downstream of the Trees Mills operation on the Porter Run and Beaver Run tributaries. The downstream monitoring points are located immediately above the confluence of these two tributaries (MP-12a and MP-12b). The upstream monitoring points are shown in Figure 5.3k.

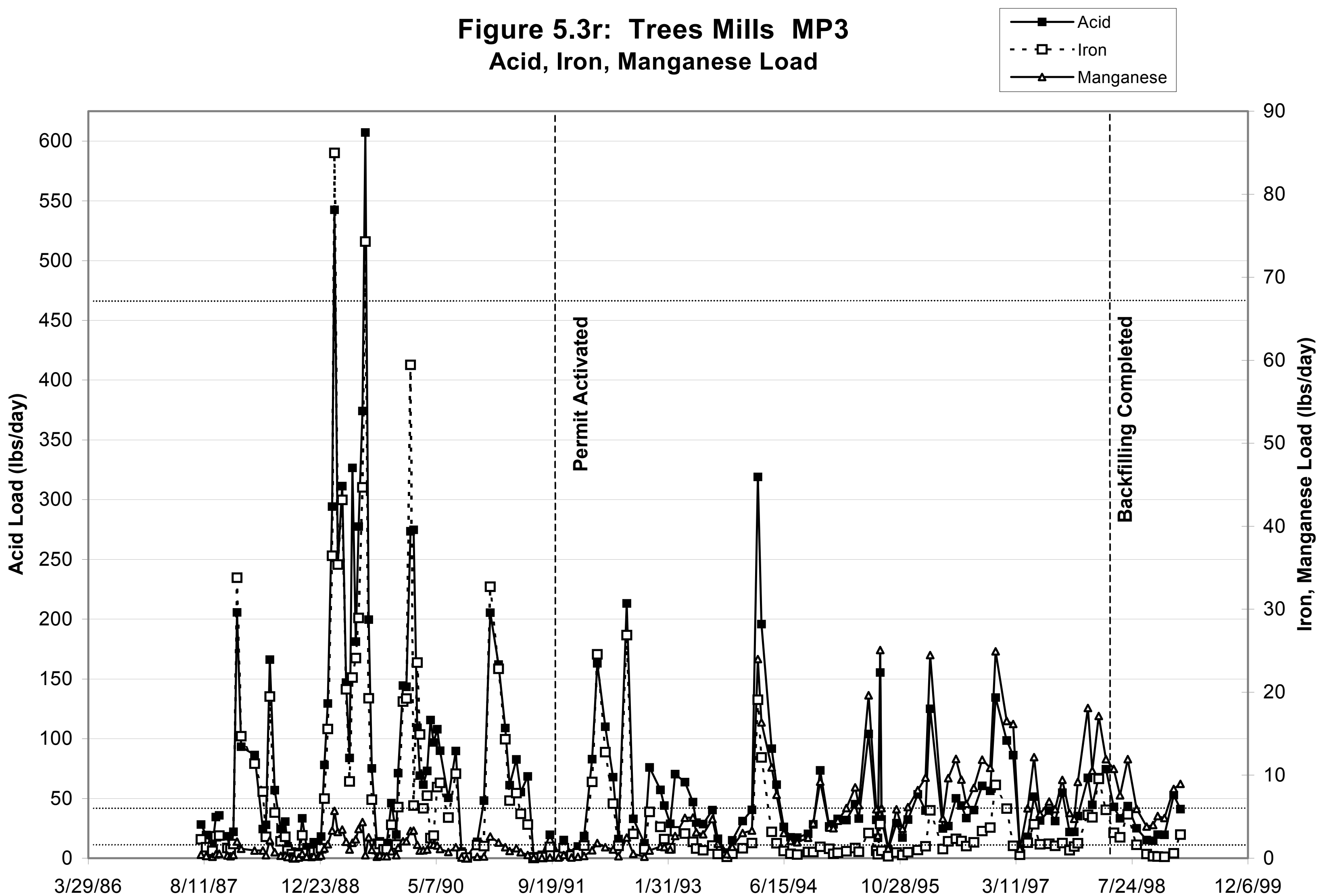


Figure 5.3r: Trees Mills MP3
Acid, Iron, Manganese Load
Acid
Iron
Manganese
Acid Load (lbs/day)
Iron, Manganese Load (lbs/day)
Permit Activated
Backfilling Completed
0
50
100
150
200
250
300
350
400
450
500
550
600
0
10
20
30
40
50
60
70
80
90
3/29/86
8/11/87
12/23/88
5/7/90
9/19/91
1/31/93
6/15/94
10/28/95
3/11/97
7/24/98
12/6/99

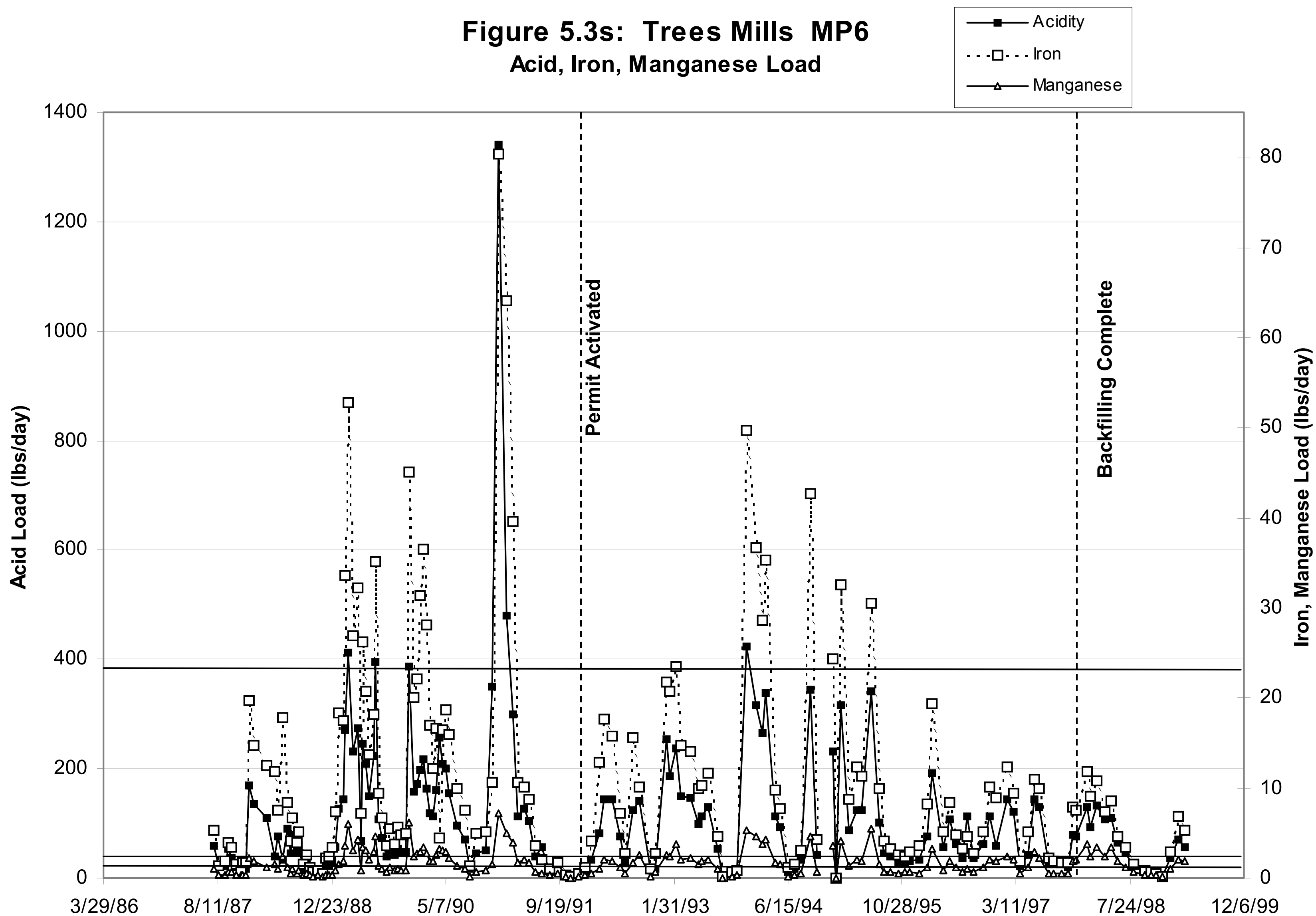
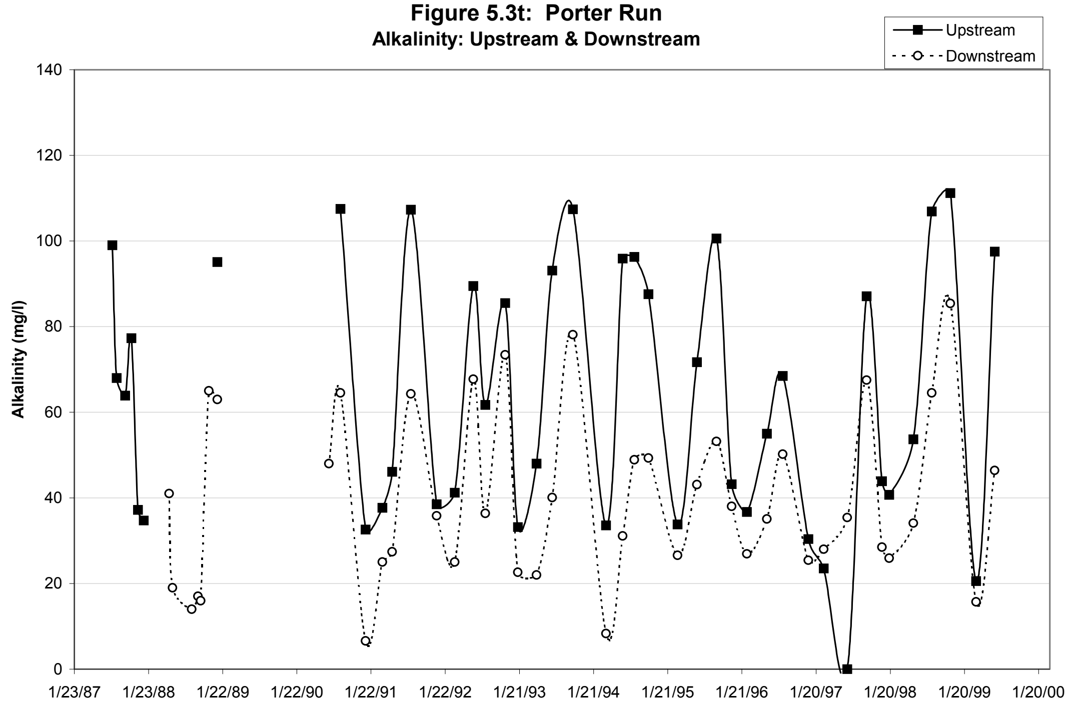


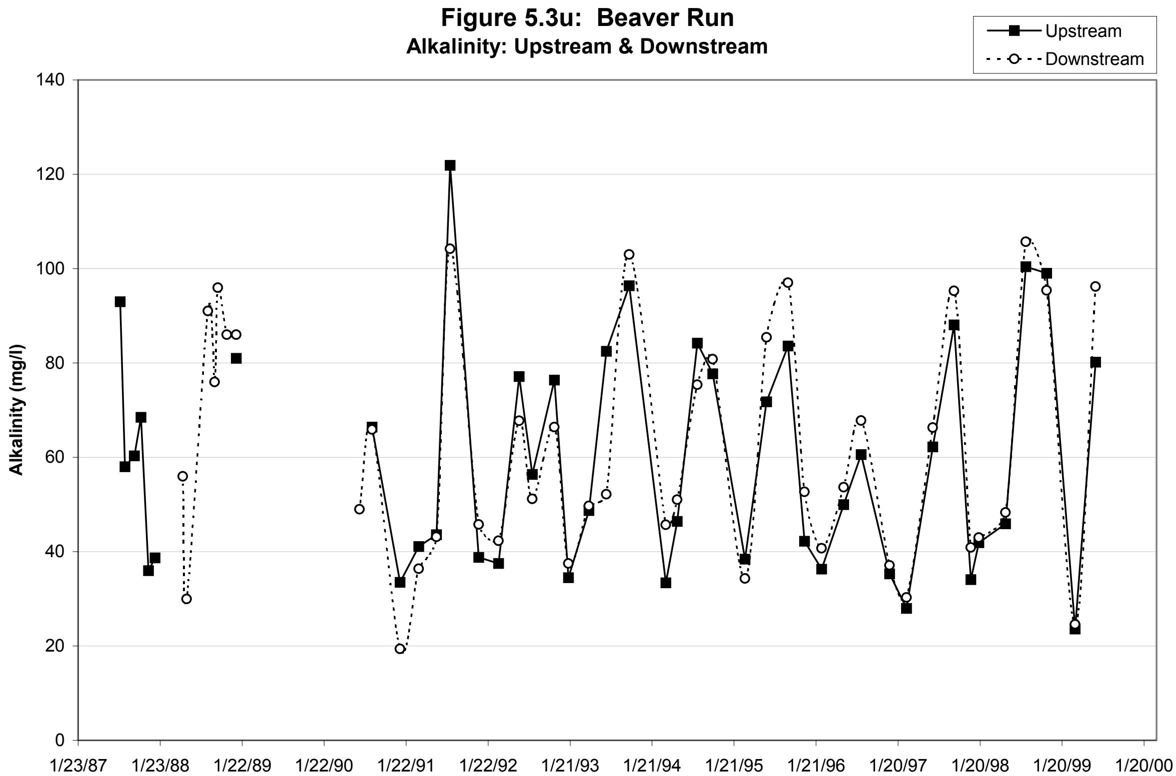
Figure 5.3s: Trees Mills MP6
Acid, Iron, Manganese Load
Acidity
Iron
Manganese
Acid Load (lbs/day)
Iron, Manganese Load (lbs/day)
Permit Activated
Backfilling Complete
1400
1200
1000
800
600
400
200
0
80
70
60
50
40
30
20
10
0
3/29/86
8/11/87
12/23/88
5/7/90
9/19/91
1/31/93
6/15/94
10/28/95
3/11/97
7/24/98
12/6/99

These two tributaries had appreciable alkalinity concentrations during the entire monitoring period (1987 through 1999), undoubtedly due to the presence of significant carbonate lithologic units in the drainage basin (e.g., the limestone underlying the Pittsburgh Coal Seam, Figure 5.3l). However, by comparing upstream and downstream alkalinity concentrations in Porter's Run and Beaver Run (Figures 5.3t and 5.3u), the subtle changes in alkalinity concentration observed are believed to be due to the reduction in acid load from the Trees Mills remining operation. In Figure 5.3t, the upstream alkalinity concentration in Porter's Run is consistently higher than the downstream alkalinity concentration during the period of record. In Beaver Run (Figure 5.3u), the upstream alkalinity concentration was higher than the downstream alkalinity pre-mining and during the first year or two of remining. However, since 1994 the trend reversed, and the downstream alkalinity concentrations are typically higher than the upstream alkalinity concentrations. It is inferred from this data that the MP-1 discharge (and other pollutional discharges) impacted the receiving stream, but the elimination or reduction of pollution loads from these discharges during and following remining increased the downstream alkalinity. The effect of this elimination, likely would be more dramatic without the presence of significant in-stream alkalinity and flow.

Figure 5.3t: Porter Run

Alkalinity: Upstream & Downstream





5.4 Conclusions

- Pre-existing discharges vary widely in flow and consequently, also in pollutant loading rates. Because there is such a large seasonal component to flow variability, it is necessary that baseline pollution load monitoring cover the entire range of seasonal conditions (generally an entire water year). Use of a partial water year may significantly under or over represent the baseline pollution load and therefore is not recommended.

- Not all discharges behave in a similar fashion. Some discharges respond steadily, with relatively small variation, while others change rapidly and by several orders of magnitude. While it is important to consider these behaviors, possibly requiring case-by-case monitoring, most discharges exhibit fairly predictable behavior, and are appropriately monitored using a monthly sampling interval and a one-year baseline monitoring period.

- Although it maybe possible to miss the most extreme high-flow events using a monthly sampling interval, as long as a consistent sample interval is used for determining and monitoring baseline, and the statistical test is not overly sensitive to extreme values, this sampling protocol should be adequate. Low flow events occur over longer periods of longer duration and should be adequately represented with monthly sampling.

- Extremely dry or extremely wet years may pose difficulties in establishing a representative baseline pollution load, but significant year-to-year variations in pollution load are rare and would be even more rare for multiple consecutive years. Seldom would it be worth the additional time and expense to require a multi-year baseline period. However, water quality monitoring should consider the possibility, though infrequent, of year-to-year pollution load variations that rise to the level of statistical significance.

- Remining-induced changes in pollution load tend to be very dramatic and can result from either significant changes in flow or significant changes in water quality. The fact that these changes are rarely subtle makes it relatively easy to design a monitoring program that can detect significant changes, while minimizing the incidence of false positives (i.e., indications of significant changes in water quality which may be due to seasonal changes or changes due to weather patterns). The monthly monitoring interval used in the case studies did adequately document pre and post-remining water quality, and was sufficient to detect significant changes in pollution loading rates.

- Less frequent water monitoring intervals are much more likely to over or under represent the baseline pollution load, and to inaccurately detect changes in pollution loading rates. Monitoring intervals that are more frequent than monthly, are generally unnecessary and may not be worth the added expense.

- Acidity and alkalinity, pH, metals, sulfates, and flow rates, often respond differently depending on the BMP used. Some BMPs may reduce flows while leaving pollutant concentrations unchanged. Sources of alkalinity may increase pH and reduce acidity, increase one or more metals and decrease others, and increase or decrease sulfates. Observing the response of individual parameters allows the analysis of BMP efficiency. This is useful for applying particular BMPs to similar situations, in troubleshooting, and in adding or modifying BMPs to achieve a desired result.

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